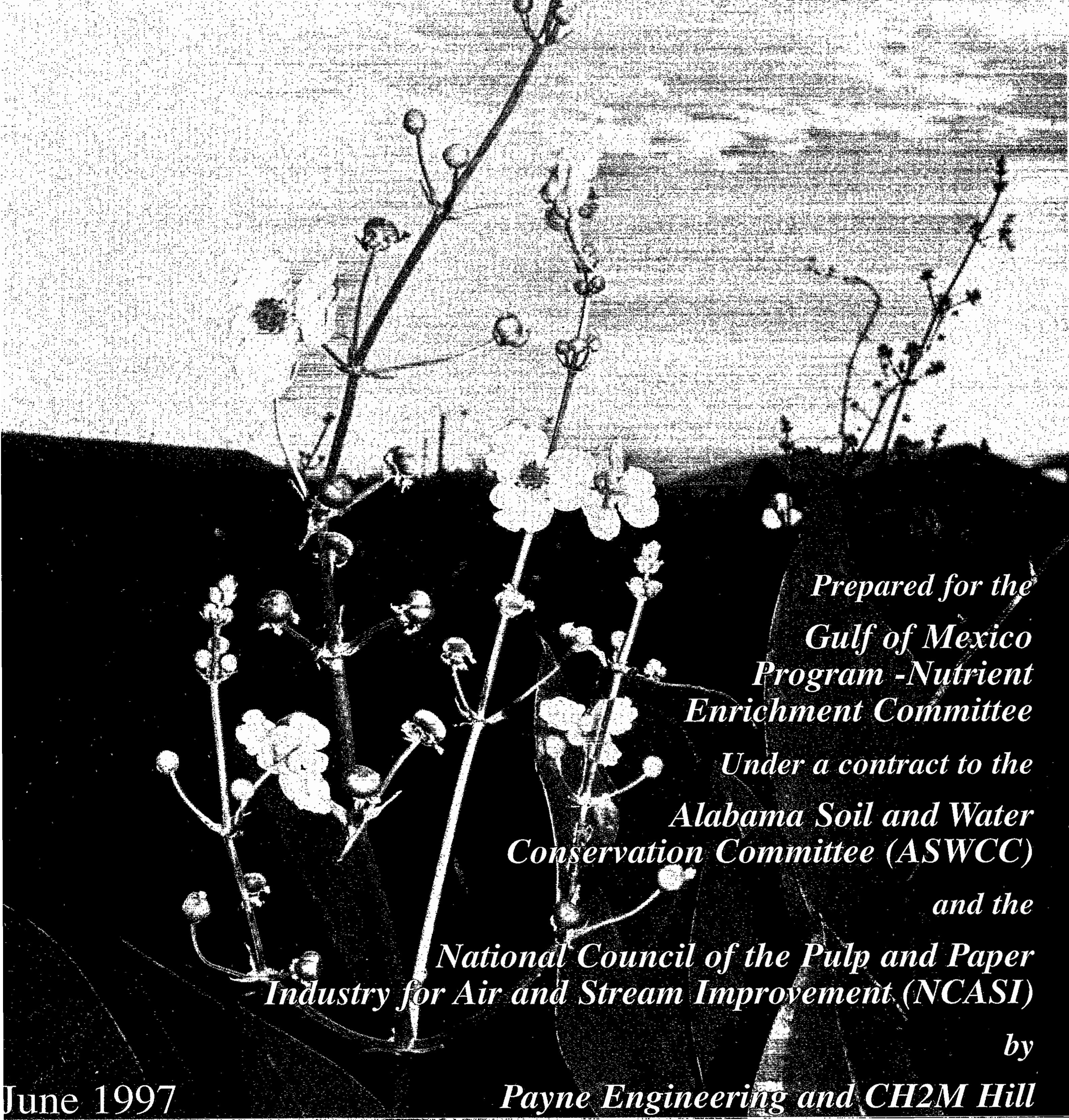
Constructed Wetlands for Animal Waste Treatment

A Manual on Performance, Design, and Operation With Case Histories



Prepared for the

Gulf of Mexico Program -Nutrient Enrichment Committee

Under a contract to the

Alabama Soil and Water Conservation Committee (ASWCC)

and the

National Council of the Pulp and Paper Industry for Air and Stream Improvement (NCASI)

by

Payne Engineering and CH2M Hill

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Constructed Wetlands for Treating Animal Wastes
Section I: Performance, Design, and Operation

*Victor W. E. Payne, Jr., PE, and Robert L. Knight, PhD.**

Introduction

Waste management can be a major problem for livestock producers who grow animals in buildings, pens, or other confined areas. The waste produced in these types of facilities can be in liquid, slurry, or solid form. Solid wastes, such as that produced at broiler facilities, are fairly easy to manage. These wastes, which might include manure and bedding, are simply scraped and hauled to land application sites at relatively infrequent intervals.

Slurries or semi-solid wastes are thick fluids usually collected in fabricated pits or tanks. These wastes are often scraped or pumped from a pit and hauled directly to the land when conditions permit. Slurry wastes are apt to have more odors when land applied than either dry or liquid wastes.

Liquid systems can be more complicated to manage and can create a much higher risk of polluting surface and ground waters. These systems are usually associated with swine, layer hens, the confinement portion of dairies, certain beef feedlot operations, and other less common facilities.

The constructed wetland, as will be shown in this publication, can be an important tool in the management of liquid animal wastes. The recently published Constructed Wetlands for Livestock Wastewater Management: Literature Review, Database, and Research Synthesis (CH2M Hill and Payne Engineering, 1997), referred to hereafter as the CWLW report, demonstrates that constructed wetlands technology has been used for many years in municipal waste systems but is relatively new with regard to animal waste systems; the vast majority of constructed wetlands for animal waste treatment have been installed since 1989. The CWLW report also illustrates that high levels of treatment can be achieved with this technology.

This document is intended to be a state-of the-art users manual on constructed wetlands for those engineers, planners, technicians, and livestock producers who have more than just a casual interest in the subject of constructed wetlands for treating livestock wastes. It will condense some of the information contained in the CWLW report, a more data-intensive companion publication to this document. It will also provide other practical information intended to help the user understand the value of constructed wetlands and how they might be included as part of an animal waste management system. The user should refer to the CWLW report if detailed background tables and other supporting material are needed.

Management of Liquid Wastes

Liquid wastes from confined animal facilities include manure, contaminated water, and other liquids and solids that enter the waste

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stream, such as spilled milk and feed, bedding material, animal hair, feathers, and broken eggs. In many cases, the volume of contaminated water in liquid systems is much greater than the volume of manure. Contaminated water includes flush water used to remove wastes and clean houses and milking facilities, spilled drinking water, runoff from open lots and buildings, and direct precipitation on lagoons and other open waste storage facilities.

There are instances in which pumping from a lagoon and directly applying wastewater to the land may not be the best option.

Over the years, livestock producers have used a wide variety of techniques and methods to manage and control liquid wastes. Many approaches to waste management have been ill conceived and have resulted in pollution of streams and lakes, as well as odor problems with neighbors.

Four factors will determine the success or failure of a liquid waste management system: proper planning, design, installation, and management. Failure in any one of these areas will result in failure of the system.

The development of a manageable method of handling liquid wastes should be addressed during initial planning using a *systems* approach. This approach recognizes that there is not a single, all-purpose method that applies to all livestock facilities and that the system developed must be site specific.

Furthermore, it views all structural, vegetative and management elements associated with waste management as part of a well organized and interrelated system. Development of the system requires careful planning and takes into account all factors associated with collecting, treating, storing, and land applying the waste. Such factors as regulatory restrictions, economics, manpower requirements, operation and maintenance, and environmental considerations are also part of a well planned system.

Table 1 illustrates the major elements and some of the components commonly used in animal waste management systems. The constructed wetland is shown as a treatment component because its purpose is to reduce the pollution potential of wastewater. If a constructed wetland is added to an existing system, which has occurred in most situations around the country to date, this addition will affect nutrient management, water management, and O&M.

The Constructed Wetland as a Treatment Component

□ The Value of Constructed Wetlands

It would appear that the most straightforward and useful way to dispose of liquid wastes is through direct pumpout or hauling from the lagoon or other storage structure to a land application site. In most cases this may be the best approach. However, there are instances in which this approach cannot be used or, possibly, should not be used. The following situations, summarized from Miller et al., (1996), Hughes et al. (1996), and Payne et al. (1996), illustrate the usefulness of a constructed wetland in a waste management system.

Table 1. Agricultural Waste Management System Functions and Components

System Function	Component Category	Typical Components
Production	Structural	Roof gutters, downspouts, diversions
	Vegetative	Grassing of diversions and around production facilities
	Management	Maintenance of leaky waters, recycling flush water, measures to reduce feed spillage, maintenance of structural components
Collection	Structural	Alleys & gutters; slatted floors; scrapers and flush systems; curbs; pumps & pipelines; fences; solids storage pads; diversions.
	Vegetative	Grassing of diversions
	Management	Maintenance of all structural and vegetative components.
Waste Transfer to Storage or Treatment	Structural	Sumps; pumps; gravity and pressure pipes; flumes; valves; weirs.
	Vegetative	Vegetation around sump boxes and along flumes
	Management	Maintenance of structural and vegetative components
Storage	Structural	Waste storage ponds, waste storage tanks, waste stacking facilities; fences; loading ramps; pumps; pipes and pipelines.
	Vegetative	Grassing around facilities for erosion control
	Management	Maintenance of structural components and vegetation; managing water levels.
Treatment	Structural	Waste treatment lagoons, composters, solid/liquid separators, settling basins, **constructed wetlands**, overland flow treatment
	Vegetative	Grassing of lagoon and wetland embankments; plants in the **constructed wetlands**.
	Management	Maintenance of structural components and vegetation; maintenance of water levels in lagoons and **constructed wetlands**
Wastewater recycling or transport to fields	Structural	Pumps; pumphouses; pipelines; valves; hauling equipment;
	Vegetative	Grassing around pumphouses, over pipelines.
	Management	Maintenance of structural components; preventing plugging of pipes and pumps with debris and struvite.
Utilization or disposal*	Structural	Irrigation and hauling equipment; biogas generators; refeeding; bedding; monitoring stations for permitted discharge.
	Vegetative	Vegetation at spreading site; diversions; filter strips; riparian zones.
	Management	Soil testing; cutting and managing vegetation; maintenance of structural components; collecting water samples.

*Disposal refers to a permitted discharge. Although possibly allowed, it is not usually recommended.

1. *Nutrient matching*: The owner of a confined feeding operation must have enough land to spread the accumulated wastewater at proper times of the year and at proper agronomic rates. If 30 acres is required to properly utilize a lagoon's contents but only 20 acres is available, the owner has a limited number of choices on how to handle this problem: (1) convert to a cropping system that can utilize more nutrients, (2) reduce the number of animals, or (3) add another treatment component to further reduce the nutrient load.

The conversion to another crop or cropping sequence may not be a viable alternative if a high-nutrient-uptake crop cannot be found; if such a conversion would require a change in the owner's harvesting equipment or labor requirements; or if the markets and other economic factors are negative. If reducing the number of animals is ruled out, then the owner *must* consider additional treatment. Here is where the constructed wetland could be a desirable alternative as opposed to the addition of another lagoon. Guidelines for determining rates of nutrient reduction and sizing the wetland are provided in a later section of this publication.

2. *Pollutant reductions:* Discharge of treated livestock wastewater is usually not a viable option. Although guidelines of the USEPA may allow discharges under certain situations (USEPA, 1995), most states do not allow discharges of treated animal wastes in any case. A survey of 13 states conducted in May 1996 (Payne et al., 1996) indicated that only four might allow a discharge after treatment in a constructed wetland, but the producer must obtain a National Pollution Discharge Elimination System (NPDES) permit and, possibly, state and local permits. Since constructed wetlands provide high removal efficiencies for BOD, TSS, fecal coliform bacteria, and nitrogen, the use of a constructed wetland to treat livestock wastewaters could result in pollutant concentrations that meet NPDES or other more restrictive limits throughout most of the year. If a discharge were allowed, the producer would have to be prepared to satisfy the sampling and monitoring requirements specified in the permit restrictions.

Irrigated wastewaters often have high concentrations of nutrients and solids

3. *Odor control:* Odors from the application of lagoon or storage pond wastes may be offensive to neighbors and could result in litigation. Since the effluent from constructed wetlands is relatively odorless compared with wastewaters from other pretreatment facilities, the wetland effluent could be stored in a downstream holding pond and then irrigated to the final application site with odor levels lower than those potentially produced by other systems.

4. *Economics:* A constructed wetland will reduce the total amount of nutrients produced from a system and, therefore, reduce the amount of land needed at the application site. This, in turn, can reduce the amount of time spent for hauling or irrigating. It can

also allow the use of smaller and more cost-effective spreading equipment. The loss in nutrient value and the loss associated with land possibly taken out of production to install the wetland might be balanced against the lower capital costs of equipment and reduced labor requirements (Hughes et al., 1996). From an economic standpoint, each system must be evaluated on its own merits to determine if the installation of a constructed wetland will provide an economic advantage.

5. *Reduced labor:* Installation of a constructed wetland could reduce land requirements at the application site to the extent that the producer could install a simple solid set irrigation system as opposed to a more labor intensive traveling gun or center pivot irrigation system. Even if the economics do not favor the wetland/solid set irrigation system, many producers would be willing forgo a small measure of economic benefit to reduce the amount of time spent in handling wastes.

6. *Aesthetics:* The constructed wetland can be a nice addition to the farm enterprise. Some very attractive, flowering aquatic plants have been used successfully to treat wastewaters; however, not all are suitable for the high strength wastes often associated with livestock wastewaters. The planner will need to determine the strength of the waste and the suitability of decorative or exotic plants to survive in such an environment. Even if the more colorful plants cannot be used, traditional plants such as cattail (*Typha* spp.) and bulrush (*Scirpus* spp.) are attractive and suitable for treating most wastewaters.

□ Potential problems

Disease transmission: Occasionally, questions are raised about the chance of diseases being transmitted by wildlife which enter the constructed wetland and then move to another location. There is no doubt that certain birds, land mammals, reptiles and insects are attracted to treatment wetlands. In the case of municipal wetland treatment systems, which have been used worldwide for decades, no disease transmission problems caused by migrating animals have ever been reported, even though many of these systems have been used as nesting sites for waterfowl.

If the wetlands do not include open water areas, bird populations will be limited to nonaquatic species, such as redwing blackbirds and yellow headed blackbirds. In other words, these birds will not normally have contact with the polluted water. Such is usually the case with wetlands for treating animal wastes.

In non-wetland situations, it should be noted that killdeer often walk on the flotsam of animal waste lagoons and egrets dine on the droppings of cattle without concern for disease transmission. It is also noted that a number of scientists and researchers have described the positive benefits to wildlife associated with municipal waste treatment wetlands (Guntenspergen et al., 1993; Lofgren, 1993; Kadlec and Knight, 1996). Thus, based on extensive experience with municipal wetlands, the limited access of waterfowl to animal waste wetlands, the already extensive access of birds to other sources of animal wastes, and the apparent lack of evidence linking treatment wetlands to health hazards, it appears that potential problems regarding disease transmission by birds associated with animal waste wetlands are minimal.

There appears to be no evidence that other mammals, reptiles, or insects have contracted any diseases from constructed wetlands or that they will migrate to other locations and, thereby, transmit diseases.

Damage by animals: Both nutria and muskrats have been a problem in animal waste constructed wetlands. These animals, if not controlled, may burrow between wetland cells and may also destroy vegetation. Vigilance is required to assure that these types of invaders are controlled. Where these problems are known to have occurred, the animals have been removed and measures were taken to prevent further access.

Cattle have also entered treatment wetlands and damaged vegetation. If grazing animals could be a problem, fencing may be required to protect vegetation, embankments, and water control structures.

□ Types of constructed wetlands

Three types of constructed wetlands could be used for treating animal wastes: surface flow (SF), subsurface flow (SSF), and floating aquatic plant (FAP) systems (Figure 1). While natural wetland systems are in some cases used for municipal treatment, they are not considered to be "constructed" wetlands, and they are not likely candidates for the treatment of animal wastes. Therefore the following discussion describes only the principal types of constructed wetlands.

1. *Surface Flow (SF) Constructed Wetlands*:

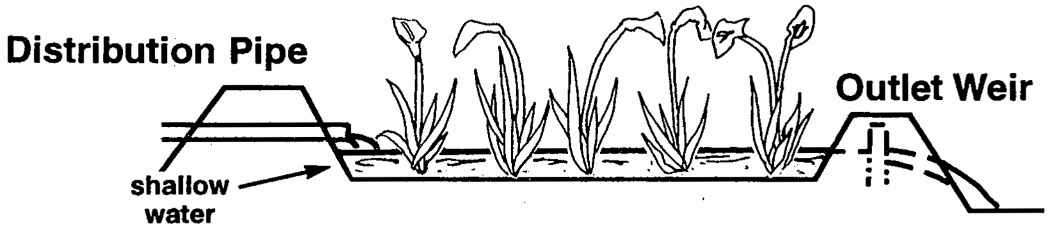
The SF wetland is the most commonly used wetland for treating animal wastes and is the only one currently recommended by the USDA Natural Resources Conservation Service (USDA NRCS, 1991).

SF constructed wetlands are shallow impoundments planted with rooted, emergent vegetation. (Emergent means the plant structure extends above the water surface.) Wastewater is treated as it passes over the bottom of the wetland and through the plants and bottom litter.

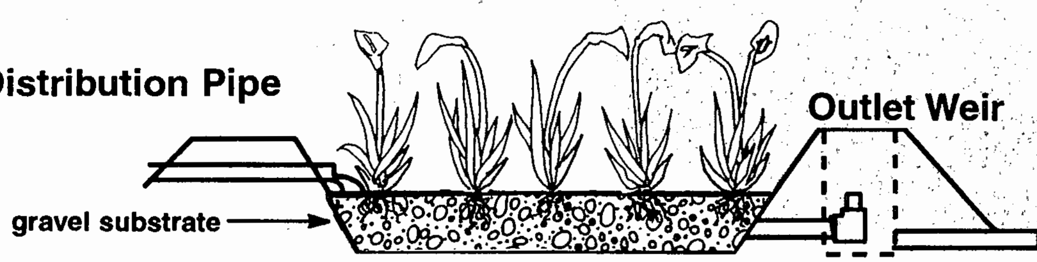
Surface flow constructed wetlands are shallow impoundments planted with rooted, emergent vegetation.

Plant uptake of nutrients by the aquatic vegetation is very small in relation to the total nutrient load in the water column; therefore, removal of nutrients from the wetland by plant harvesting is considered unnecessary. Instead, nutrients and biodegradable organics in the wastewater are efficiently converted and removed in the SF wetland primarily through the natural assimilative capacity of the microbial flora (principally bacteria and fungi). The various mechanisms involved in treatment are discussed in detail under *Treatment Mechanisms*.

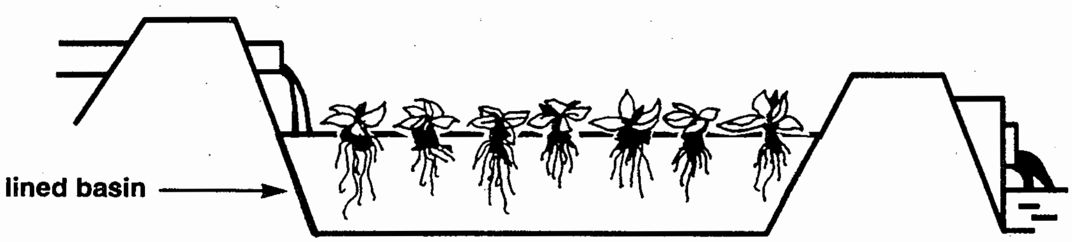
The advantages of the SF wetland include (1) their ability to efficiently treat high strength wastes associated with discharges from animal waste lagoons and other



Surface Flow Constructed Wetland



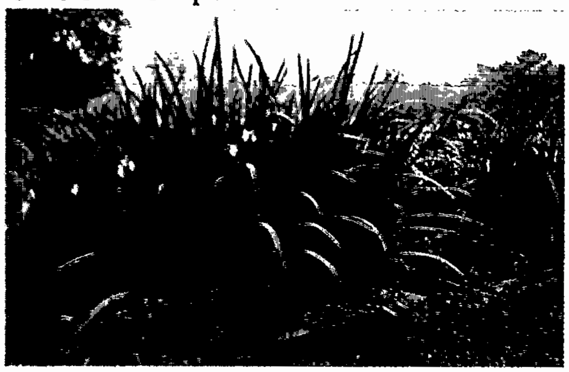
Subsurface Flow Constructed Wetland



Floating Aquatic Plant (FAP) System

Figure 1: Types of Constructed Wetlands for Waste Treatment

pretreatment facilities; (2) their relatively low cost compared with subsurface systems; (3) their relative ease of management; and (4) their ease of repair and maintenance should problems occur. For these reasons and the fact that USDA currently recommends only SF systems for animal waste treatment, the surface flow constructed wetland will be the focus of this report.



An on-site constructed wetland successfully treats domestic wastewater

2. *Subsurface Flow (SSF) Wetlands:*

The SSF wetland contains gravel, rock or soil media, placed below ground level, through which the wastewater passes in a horizontal direction. The water level remains just below the surface elevation of the porous bed. Emergent hydrophytic plants are grown on the surface with the roots penetrating the saturated, porous medium. The bed and the penetrating roots contain a large surface area on which bacteria grow; thus, the system functions somewhat like a rock trickling filter at a municipal wastewater treatment plant. But unlike the trickling filter, the roots appear to provide microscopic zones of aeration which aid the treatment process. (See *Vegetation.*)

SSF wetlands have an advantage in cold climates because treatment occurs below the ground surface, and bacterial communities are thereby insulated somewhat from the frigid air. In addition, SSF systems have virtually no odors, and mosquitoes are not a problem. When properly designed, gravel based wetlands are highly efficient at removing biodegradable organic matter and nitrates from wastewater.

When used to treat dilute wastewaters, SSF wetlands can be planted with various types of attractive plants such as canna lilies, elephant ear, and spiderwort (*Canna flaccida, Colocasia esculenta*, and *Tradescantia* spp., respectively). Such systems are being used successfully in rural areas to treat domestic wastewater, especially for single family residences.

A major disadvantage of the SSF wetland is the potential for plugging, causing water to pool on the surface. The potential for plugging would be much higher for livestock systems, which usually contain very high solids concentrations. In addition, the installation cost is typically at least five times more than for the same area for SF systems (Kadlec and Knight, 1996). Thus, because of the potential for plugging and the high costs of installation, SSF systems are not being seriously considered for the treatment of livestock wastes. If these systems were to be used at all, it would likely be in colder climates and only for certain components of small scale livestock facilities having wastewaters with a low solids content and low water volume.

3. *Floating Aquatic Plant (FAP) Systems:*

Several different FAP systems have been used for wastewater treatment. These systems commonly use floating aquatic species such as duckweed (*Lemna* spp. or *Spirodela* spp.) or water hyacinths (*Eichornnia crassipes*). This vegetation takes up nitrogen, phosphorus, and metals, which can be physically removed by plant harvesting. In addition, microbes attached to plant roots assimilate biochemical oxygen-demanding substances, nitrify ammonium (NH_4) to nitrate (NO_3), and denitrify NO_3 to nitrogen gas. The dense vegetative mat that forms on the water surface effectively shades out algal populations.

Intensively managed FAP systems can meet low effluent limits for nutrients without using chemical additions. Since a limited number of FAP systems are currently operating, very little information is available on design, costs, and performance with highly enriched livestock wastewaters. Thus, it is difficult to compare FAP systems with other treatment wetland technologies.

However, based on data for SF and FAP municipal systems, FAP systems have lower reaction rates, higher construction and operating costs, more sensitivity to cold temperatures, and more susceptibility to plant pests and pathogens. Polyculture (multiple species) systems that use a combination of floating aquatic plant species offer an alternative with less intensive pest management requirements. Also, FAP systems that use greenhouse enclosures in colder climates can be considered for small livestock operations with relatively dilute wastes.

□ Treatment Mechanisms within Wetlands

A number of physical, chemical, and biological or biochemical treatment mechanisms occur within a treatment wetland. These mechanisms are often interrelated; some are simple and some complex. In addition, some of the mechanisms are not fully understood technically or in terms of their overall contribution to the treatment process.

The mechanisms are listed below with a brief commentary on each. More detail will emerge in subsequent discussions.

Some of the treatment mechanisms within wetlands are not fully understood technically or in terms of their overall contribution to the treatment process.

1. *Biochemical conversions*: The largest single factor affecting treatment is the conversion of various chemical compounds through the activity of bacteria and fungi. Organic compounds, represented analytically through such tests as biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and volatile solids (VS), are reduced under anaerobic conditions to innocuous end products such as carbon dioxide (CO_2) and methane (CH_4). Under aerobic conditions the end products are CO_2 and water.

Nitrogen is converted by microorganisms from the organic form (Org-N) to ammonia forms ($NH_4^+ + NH_3$). If aerobic conditions are present, the ammonia will then be converted to nitrite (NO_2) and nitrate (NO_3). If the nitrate then enters an anaerobic zone, it can be converted by bacteria to a gaseous

Table 2 . Typical ammonia concentrations in the supernatant and sludge of anaerobic treatment lagoons for dairy, swine, and poultry.*

Type	**$NH_4^+ + NH_3$-N concentrations (mg/L)**	
	Supernatant	**Sludge**
Dairy	200	2498
Swine	219	758
Poultry	549	918

*Source: Modified from USDA-NRCS, 1992.

form (principally N_2) which can be liberated to the atmosphere. (See nitrogen cycle, Figure 2.)

Organic phosphorus and other compounds also undergo biochemical conversions. Unlike nitrogen, phosphorus and some other chemical constituents are conservative and do not have a gaseous state; thus, they will be "removed" through other mechanisms noted below or will be discharged.

2. *Settling/filtration*: These are perhaps the simplest mechanisms and involve the deposition of solids on the floor of the wetland and entrapment by plant stems and bottom litter. Both floating matter and other suspended material may be retained through these mechanisms. The organic fraction of the solids will be degraded biochemically. Some of the inert material or slowly degradable material may eventually become part of the peat bed which forms through accretion.

3. *Accretion*: This term refers to the physical buildup of material on the floor of the wetland as new soil. Recent additions of loose vegetative litter or thatch are not considered part of the accreted material. The accretion rate will typically be less than one-half inch (1.2 cm) per year and will consist of settled wastewater solids, the remnants of decayed litter, and microbial biomass. Accretion will be a principal removal process for phosphorus and certain metals.

4. *Volatilization*: This refers to the loss of constituents to the atmosphere in gaseous form. The process can be biochemical or strictly chemical. The conversion of NO_3 to gaseous nitrogen through denitrification has already been noted under *Biochemical conversions* above and will be discussed further under *Vegetation*. The discussion here will focus primarily on the volatilization of ammonia because of its importance in animal waste management systems.

There are only two natural mechanisms by which nitrogen can be lost to the atmosphere from a waste treatment system: ammonia volatilization and denitrification (see Fig. 2). In order for denitrification to occur (an anaerobic process), nitrogen must first be converted to nitrate (NO_3) from the ammonia form (an aerobic process).

Livestock pretreatment lagoons are nearly always anaerobic; thus, nitrogen will be in the organic and ammonia forms only. Typically, the supernatant will contain 20 to

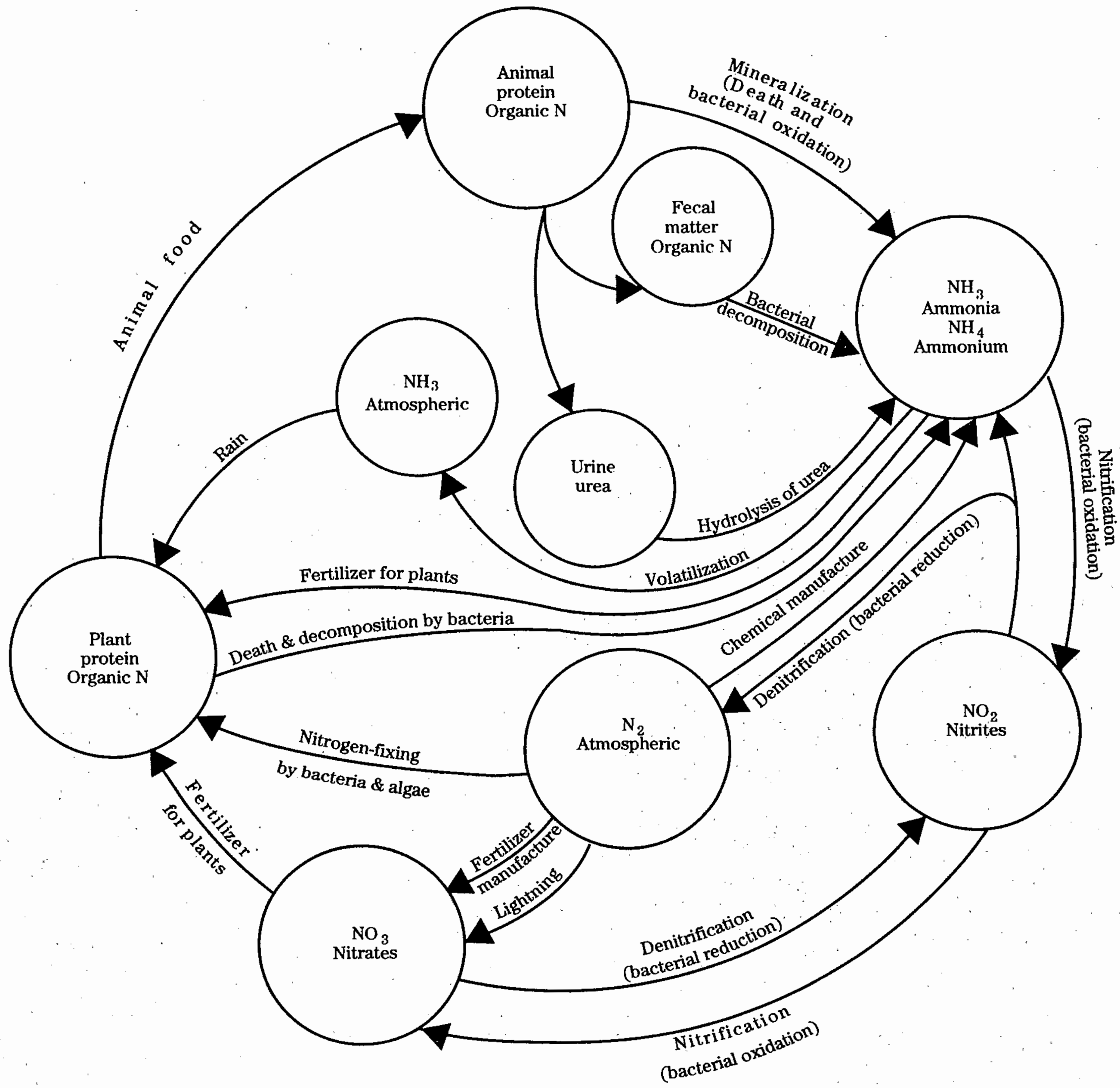


Figure 2: The Nitrogen Cycle (Ref. AWMFH)

40 percent organic nitrogen and 60 to 80 percent ammonia. The concentrations of ammonia nitrogen in the supernatant of animal waste lagoons will be much higher than those of *untreated* domestic sewage, which, for a medium strength waste, will only be about 25 mg/L. (See Table 2.) Since there is virtually no oxygen present within the water column of most anaerobic animal waste lagoons, the conversion of ammonia to nitrate cannot occur and, hence, without nitrate, denitrification is impossible. While some nitrification may occur at the air/water interface of an anaerobic livestock lagoon where oxygen diffusion could occur, it appears that volatilization rather than nitrification/denitrification may be the principal mechanism for nitrogen loss within lagoons.

It should be noted, however, that only a small fraction of dissolved gaseous NH_3 is usually present in livestock wastewaters, with the amount being a function of pH and temperature. The higher the pH and the warmer the water, the large the fraction of NH_3 present. Table 3 illustrates the shift in concentration between NH_4^+ and NH_3.

The pH in animal waste lagoons is usually in the range of 7.0 to 8.0. From late spring through fall, water temperatures of lagoons sampled in Alabama were between 25 and 30 degrees C, with pH ranging from 7.2 to 7.5.

While un-ionized ammonia would be only about three percent of total ammonia in these lagoons, much more than this amount could be lost through volatilization. The reason for this is explained by the following equation:

$$NH_4^+ \rightleftharpoons NH_3\uparrow + H^+$$

Table 3. Percent un-ionized ammonia (NH$_3$) in aqueous ammonia solutions.*

Temperature (°C)	pH					
	6.0	6.5	7.0	7.5	8.0	8.5
15	0.027	0.087	0.27	0.86	2.7	8.0
20	0.040	0.13	0.40	1.2	3.8	11.0
25	0.057	0.18	0.57	1.8	5.4	15
30	0.080	0.25	0.80	2.5	7.5	20

*Source: modified from EPA, 1974.

The equation indicates that if NH_3 in an aqueous solution is lost as a gas, the equation shifts to the right to maintain the equilibrium. Consequently, as NH_3 at the water/air interface of a lagoon is lost to the atmosphere, more NH_4 is converted to NH_3 which, in turn, is available for volatilization.

In municipal treatment, "ammonia stripping" towers are used to drive off un-ionized ammonia, a process which is facilitated by fans or blowers and by raising the pH above 10. In lagoons only the movement of wind across the surface enhances the volatilization rate. In addition, temperature is an important factor in this process. In stripping towers for municipal wastewaters, 90 to 95 percent of the ammonia is typically driven off at 68°F (20°C), but only about 75 percent is lost at 50°F (10°C) (Corbit, 1989).

It appears, therefore, that the lagoon accomplishes ammonia stripping but at a rate much slower than municipal systems on a unit area basis. While the amount lost over the total surface area of a lagoon is obviously great, there is some question as to whether or not ammonia volatilization is the principal mechanism in nitrogen removal from livestock wetlands.

Ammonia gasification over wetlands vegetated in rice and fertilized with ammonium fertilizer has been studied, and the loss rates were found to be comparable to plant uptake for dense stands of macrophytes (Freney et al., 1985). Kadlec and Knight (1996) summarized other studies dealing with ammonia gasification for municipal systems and an acid bog (Billmore et. al., 1994, and Hemond, 1983). They conclude that "volatilization typically has limited importance, except in specific cases where ammonia is present at concentrations greater than 20 mg/L."

It would appear, therefore, that ammonia volatilization may be the most significant mechanism for nitrogen loss within constructed wetlands which treat animal wastes. The principal reasons are as follows:

a. Total ammonia concentrations in the pretreated wastewater entering livestock constructed wetlands are nearly always greater than 20 mg/L, the concentration above which volatilization becomes important; often it will exceed 100 mg/L.

b. Most pretreated livestock wastewaters discharged to treatment wetlands are typically anaerobic, which means that nitrification in the surface flow will be limited and, consequently, any subsequent denitrification will also be limited.

c. Limited research on rice fields treated with inorganic ammonia fertilizer indicates that ammonia volatilization is occurring, and it is expected that the conversion rates would be even higher for organic wastes with high ammonia concentrations.

Further research related to ammonia volatilization from animal waste constructed wetlands is needed. (See additional discussion on ammonia losses under *Adsorption, Evapotranspiration,* and *Vegetation.*)

It would appear that ammonia volatilization may be the most significant mechanism for nitrogen loss within wetlands used to treat animal wastes

5. *Adsorption*: Adsorption refers to the binding of one constituent to another through the chemical attraction of oppositely charged particles. Positively charged compounds such as the ammonium ion (NH_4^+) are attracted to negatively charged clay particles. Various forms of phosphorus can be bound with calcium, aluminum and iron, all common constituents of soils. It is likely that initially high rates of phosphorus and NH_4^+ removal in the early years of wetland life may be attributed to adsorption within the soil matrix. As the wetland matures and more of the adsorption sites

become occupied, the apparent net treatment efficiency for these chemicals drops.

6. *Evapotranspiration*: As wastewater flows over the surface of the soil in the wetland, an amount of water approximately equal to that required by the plants for evapotranspiration (ET) is drawn into the root zone. (This assumes that the wetland was properly sited and that no lateral subsurface water enters the root zone.) The average ET rate for

Lemna is commonly found in animal waste constructed wetlands.

vegetated wetlands is approximately equal to lake evaporation rates (70 to 80 percent of pan evaporation). Thus, a geographic area with 36 inches (92 cm) of annual lake evaporation will extract from the overlying water about 3 ft^3 (2.83×10^{-2} m^3) of water per year per square foot (0.009 m^2) of wetland surface. A livestock wetland with wet surface dimensions of 100 x 400 ft (30.5 x 122 m) would withdraw about 120,000 ft^3 (3,396 m^3) or 897,000 gallons of water per year. Evapotranspiration becomes especially important in areas with low rainfall and high evaporation rates.

Evapotranspiration rates will affect hydraulic retention time (HRT), which is an important factor in design. In addition, since ET relates directly to the amount of wastewater drawn into the soil profile, it is an important factor in pollutant removal associated with adsorption and, possibly, nitrification/ denitrification that may occur within the root zone (see *Vegetation*).

7. *Nutrient uptake*: Wetland plants extract nitrogen, phosphorus, potassium and various minor nutrients from wastewater. These nutrient removal rates may be significant during initial development of wetland plant biomass. However, the majority of these nutrients will be recycled back to the water on an annual basis, resulting in a relatively small net removal rate by the plants compared with the total amount fed to the system. For this reason, harvesting is not a viable alternative for improving nutrient removal where most non-commercial wetland species are concerned.

□ Vegetation

A wide variety of wetland plant species have been used in or have invaded and adapted to the wastewater environment of constructed wetlands, especially in municipal systems. Guntenspergen et al. (1989) listed 17 emergent species, 4 submerged species, and 11 floating species that have been used in constructed wetlands for wastewater treatment. The pollutant concentrations in livestock wastewaters are typically much higher than in municipal systems; thus, some species which have adapted to municipal systems will not survive in livestock wastewaters.

Types of wetland plants: Wetland plants may be broadly classified as floating or rooted. The floating, unattached vegetation includes such common plants as duckweed (*Lemna* spp.), water hyacinths (*Eichhornia crassipes*), and algae in a wide variety of species. Algae and duckweed will often colonize in the open spaces of livestock wetlands. The extent to which these species are successful is limited by the amount of open space and the shade provided by the rooted emergent species. While the floating plants may invade livestock constructed wetlands, they are not currently recommended for the purposeful inclusion in these systems. Lemna and water hyacinths would have to be harvested to be most effective, and such labor intensive systems would not be welcome by most livestock producers. Thus, no further discussion of this type plant will be provided here.

Rooted plants for surface flow constructed wetlands: Within the rooted group are the submerged, floating, emergent herbaceous, and emergent woody plants. These are discussed briefly below, with indications of their possible use in livestock constructed wetlands.

1. Submerged aquatic plants may grow in the water column of deeper pools within wetlands. Through photosynthesis, they can release large quantities of dissolved oxygen directly into the water column and, in turn, promote organic decomposition and nitrification. Unlike some forms of algae, submerged aquatic plants do not typically add to significant increases in suspended solids. In most enriched wetlands where floating plants cover the deep zones, submerged aquatic plants will be shaded and unable to compete effectively for light. Their use in animal waste treatment wetlands should be the subject of research.

2. Floating, rooted aquatic plants include such species as pennywort (*Hydrocotyle* spp.), water lilies (*Nymphaea* spp.), spatterdock (*Nuphar* spp.), and pondweeds (*Potemogeton* spp.). The roots of these plants can extend from 4 to 25 inches (10 to 60 cm) into the water column, depending on the wastewater characteristics, and those rooted in the bottom can be much longer. The cover they provide can significantly influence water temperature. By inhibiting the growth of algae and reducing temperatures, the floating rooted plants can also influence dissolved oxygen concentrations. Likewise, the cover provided by these plants may also inhibit ammonia volatilization.

Pennywort spreads between the emergent plants at this swine waste treatment wetland.

Pennywort is a natural invader of the swine wastewater constructed wetland project at Sand Mountain, Alabama. It roots at the edge and then grows out as a floating mat over deeper water. At Sand Mountain it has successfully filled open areas between the emergents in the primary cells.

3. Emergent herbaceous plants are rooted in the soil and have plant structures that emerge or stand upright above the surface of the water. The herbaceous nature of these plants includes non-woody structures that allow the plant to stand erect without the support of the surrounding water. These plants have lenticels (small openings in the leaves and stems) that allow air to move in and out; vascular or aerenchymous tissue that allows gaseous diffusion or air convection through the length of the plant; and extra physiological tolerance of chemical by-products resulting from growth in the anaerobic soil environment (Kadlec and Knight, 1996).

The emergent herbaceous plants are the only ones currently recommended for planting in constructed wetlands used for livestock waste treatment. Although a wide variety of plants have been used in municipal systems, the selection becomes more limited for those livestock systems with high concentrations of BOD_5 and ammonia.

The most common emergent herbaceous aquatic plants in treatment wetlands, including those for livestock wastes, are cattails (*Typha* spp.), bulrush (*Scirpus* spp.), and common reed (*Phragmites* spp.). Plants such as duck-potato (*Sagittaria* spp.), giant cutgrass or American wild rice (*Zizaniopsis milicaea*) and other varieties have also performed well in livestock constructed wetlands. Data on the level of treatment or the biomass produced by these different species in animal waste wetlands are limited. (See Appendix B for typical species used.)

A variety of planted and naturally colonizing herbaceous aquatic macrophytes might exist in any given treatment wetland. In fact, polytypic stands of vegetation are better than monotypic stands for the wetland's ecological balance. When monotypic stands of cattail or bulrush have been studied, research has indicated no clear advantage of using specific plant species for reducing BOD_5, TSS, TN, or TP in surface flow treatment wetlands (Knight, 1996).

4. Emergent woody plants are categorized as shrubs, trees (canopy and subcanopy), or woody vines. The distinguishing characteristics of woody vegetation include its bark, non-leafy vascular structures, decay-resistant tissues and relatively long life. In general, woody plants are larger than emergent herbaceous wetland plants and may shade out smaller species.

A variety of woody plants have been used in municipal treatment wetlands. In the southeast, the most common tree species used in waste treatment include cypress (*Taxodium* spp.), willow (*Salix* spp.), ash (*Fraxinus* spp.), and gum (*Nyssa* spp.). In the north, species of willow along with spruce (*Abies* spp.), birch (*Betula* spp.), and alder (*Alnus serrulata*) have been used.

Woody aquatic plants would probably not be useful in constructed wetlands for livestock wastewaters except in the tertiary phase and where the system can be controlled to allow alternate periods of wetting and drying. Guntenspergen et al. (1989) indicate that "few woody species survive in permanently flooded soil." While species such as willows, cypress, and blackgum can, indeed, survive continuous flooding, they may not survive the high organic and nitrogen loadings typical of treated livestock wastes. More information is needed on the various woody species before recommending them for use with animal waste wetlands.

The role of emergent herbaceous wetland plants in the treatment process: The herbaceous emergents have unique features that help them survive in an otherwise hostile environment. Many can withstand continuous flooding and anoxic soils, and a few can thrive and proliferate in wastewaters with high pollutant loads. Certain exotic species (elephant ear, canna lilies, calla lilies, etc.) have done well in domestic, on-site sewage treatment wetlands, but many of these have failed in the livestock wastewater environment. In addition, some exotics cannot withstand the harsh winters outside the lower to middle South.

The primary function of the herbaceous emergents is to facilitate waste treatment; that is, they provide the means through which the treatment mechanisms can occur. As facilitators, the plants play several roles in the treatment process. These roles are noted below and are explained in terms of the treatment mechanisms already noted.

1. As a source of microbial substrate: The wetland plants provide substrate for bacteria and fungi, the source of biochemical conversions of pollutants. This substrate is important as a source of reduced carbon that provides required energy for microbial growth. It also provides a large surface area upon which the microbial populations grow. Reed et al. (1995) indicate that the micro-organisms which populate the submerged plant stems, fallen leaves, roots, and rhizomes are responsible for much of the treatment within the wetland. Kadlec and Knight (1996) suggest that the submerged substrate, comprised of a complex mixture of plant litter in various stages of decomposition and its highly productive biological communities, is responsible for as much as 90 percent of the overall treatment within the wetland. Thus, the principal function of the emergent vegetation in most treatment wetland systems is to provide the substrate important in treatment (Kadlec and Knight, 1996). As the wetland's surface area increases, so also does the substrate surface area and, hence, the overall treatment efficiency of the wetland, assuming complete submergence of the litter and adequate contact time (hydraulic retention time).

The primary function of the herbaceous emergents is to facilitate waste treatment.

2. As a facilitator of nitrification / denitrification: The process of converting ammonia to nitrate and then to nitrogen gas within a wetland depends upon having both aerobic and anaerobic conditions. In order for ammonia to be converted to nitrate, aerobic conditions are required for the obligate nitrifying bacteria. Then for the nitrate to be converted to nitrogen gas, anaerobic bacteria are required. The unique properties of the emergent macrophytes may make this possible.

All vascular plants are designed to transfer oxygen from the surrounding air or water into their roots via aerenchymous tissue when conditions prevent normal O_2 uptake by the roots and rhizomes. In the aquatic environment, direct oxygen transfer into the roots is greatly restricted. When the surrounding water contains oxygen demanding organics, totally anoxic conditions may exist and very little dissolved oxygen would be available within the root zone. Under these conditions, the plants draw atmospheric oxygen into the above-water portions of the plant through its lenticels and pass it to the roots via aerenchymous tissue. The amount of oxygen transported in this manner typically ranges from 2.08 to 12 g $O_2/m^2/d$ (Brix and Schierup, 1990; and Armstrong et al., 1990), although higher values have been reported. In some cases, excess O_2 becomes available which exudes from the roots and rhyzomes. This creates aerobic microsites around the roots which can provide a limited source of oxygen for the nitrifying bacteria (Reed et al., 1995; Kadec and Knight, 1996). Brix and Schierup (1990) reported a net release of only 0.02 g $O_2/m^2/d$ through the roots of *Phragmites australis.*

Once ammonia is converted to NO_3, either within the water column or within these microsites, the dissolved NO_3 can diffuse into the surrounding anerobic zone where denitrifying bacteria convert it to nitrogen gas (N_2O or N_2). Information from field-scale treatment wetlands is still scarce on how much oxygen is transferred to the root zone or how much nitrification or denitrification occurs (Reed et al., 1995). Wetland systems are so complex in terms of types of plants, soils, and a host of other related factors which could influence oxygen transfer and biological activity, that the loss of N, however it occurs, is currently explained in terms of general rate constants based on influent and effluent sampling rather than on kinetics of individual microbial processes (Kadlec and Knight, 1996).

3. As facilitators of soil adsorption: As noted under Treatment Mechanisms, the plants draw wastewater into the soil profile to satisfy their normal water requirements. The amount is determined by the transpiration rates of the plants. By drawing wastewater into the soil and around the root zone, the plants facilitate adsorption of ionized pollutants onto soil particles and the subsequent nitrification of ammonia and denitrification of nitrates, as noted above.

4. As a user of nutrients: Plants utilize nitrogen, phosphorus, potassium and the full range of minor nutrients. The amount taken up is usually small in relation to the total pollutant load, and this process becomes important only if the plants are harvested. Otherwise, a high percentage of the nutrients that are taken up return to the system during plant senescence. The remaining minor fraction may be lost as accretion of new soil.

The loss of N, however it occurs, is currently explained in terms of general rate constants developed from sampling many wetlands.

5. As a filter: The plant stems and the litter from the plants entrap solids. Thus, the plants facilitate the breakdown of organic solids by detaining this material and allowing time for biochemical conversions to take place. The plants also slow the movement of water and promote settling.

6. As a source of shade: By shading the water, plants help regulate water temperature and decrease the light available for algal growth. The reduction in algae concentrations will provide an attendant reduction in suspended solids concentrations in the wetland effluent.

7. As a source of new soils and sediment: As vegetation dies and as incoming sediment is trapped, a layer of material gradually develops in a process called accretion. The accretion rate is usually less than 0.5 in (1.3 cm) per year. Some of the phosphorus, nondegradable suspended solids, and metals are permanently trapped in this layer. The effects of accretion should be considered in designing embankments.

Planning for a SF Constructed Wetland

System planners must be keenly aware that the various elements selected for a waste management system interact with one another. If, for example, a structural element is changed or added in the planning process, such a change could affect the amount of nutrients produced or the amount of water that must be handled. Likewise, if it is found that the land area for spreading wastes is limited, the planner may have to modify the treatment components to reduce nutrient production. For this reason, an overall waste management plan, and not an isolated nutrient management or water management plan, should be developed. Such a plan ties the system together on paper, relating planning, design, installation, and management factors. The USDA Agricultural Waste Management Field Handbook provides excellent information on the many factors to consider in developing an agricultural waste management system (AWMS) plan (USDA, 1992).

A number of factors must be considered when planning for a surface flow constructed wetland. Listed below are some of the key factors to consider with a brief explanation of each. Professionally trained engineers, soil scientists, agronomists and others should be consulted on site-specific details and methodologies.

☐ Pretreatment

Wastewaters from all confined animal feeding operations must be treated in a lagoon, waste storage pond, or settling tank prior to being discharged to a constructed wetland. This requirement is specified in NRCS guidelines (USDA, 1991) and is absolutely essential. *Untreated* wastewater from animal confinement facilities will have concentrations of solids, organics, and nutrients that would kill most wetland vegetation. In fact, the concentrations of pollutants in the effluent from some pretreatment units will stress or kill some types of wetland vegetation.

Caution should be used with older pretreatment units that have never had any sludge removed. In these systems, wastewater influent may pass over the top of the sludge in a narrow band with very little treatment occurring; thus, the effluent will be unsuitable for discharge to the wetland. It is imperative that sludge depth be determined in these older systems and that samples of the effluent be analyzed. A wetland should not be installed until the pretreatment unit has been renovated. The life of the pretreatment unit, the anticipated sludge buildup rate, and the future need for cleanout should be factored into the AWMS plan.

☐ Wastewater characterization

Waste characterization can be accomplished by *estimating* the pollutant loads or by *analyzing* the supernatant (the surface liquid) of the pretreatment unit. If this is a new system and the pretreatment unit has not yet been installed or is not fully operational, then estimates will have to be used.

If a lagoon or other pretreatment unit is in place and nearly full, samples of the supernatant should be taken and analyzed for TKN, NH_4-N, TP, BOD_5, TSS, and pH. Ideally, samples should be collected during several months to reflect both warm and cold season effects.

Estimates of wastewater strength can be made using tables and other information in the NRCS Agricultural Waste Management Field Handbook (AWMFH) or in other professional engineering publications. (See Appendix C for sample tables.) In using these methods, the planner should be sure to evaluate or estimate the pollutants of concern within only the supernatant (the liquid portion which will overflow into the wetland) and not that in the entire pretreatment unit (sludge plus supernatant). Thus, an anaerobic lagoon may reduce the nitrogen load by 80 percent, according to some methods of estimating; however, much of the remaining 20 percent is contained in the settled sludge. In other words, only about 10 percent of the original N may be available for discharge to the wetland via the supernatant.

Wastewater must also be characterized by volume. This includes the volume of manure, flushwater and other constituents. (See *Management of liquid wastewaters* above and *Hydrologic and climatologic data*, below, for further discussion on volume considerations.)

☐ Site evaluation

An on-site evaluation is essential to obtain vital information on the physical suitability of the site. Such factors as soils, depth to bedrock, and land area should be investigated, but the evaluation should also include an estimate of the potential impacts of the wetland on the surrounding area. In addition to a visual inspection, testing, and sampling, the planner should use soil maps, contour maps, aerial photos, and other similar tools, if available, to help with the assessment. Some factors to consider in making a site evaluation are discussed below:

1. Soils: Soil borings or backhoe pits should be dug at several locations within the boundaries of the proposed wetland site. Borings or pits should extend to a depth of at least one foot below the constructed bottom of the wetland to identify permeable seams and shallow bedrock and to generally characterize soil type.

In order to reduce the potential for seepage, soils should contain a relatively high fraction of clayey material. Soils classified as clay, sandy clay, sandy clay loam, or clay loam would be suitable for the site. Clayey soils will inhibit the root growth of nearly all plants to some extent. However, plants such as cattails, bulrushes, and reeds adapt to these type soils, as noted under *Vegetation*.

If the soil in the top 12 to 15 inches (30.5 to 38 cm) is highly permeable (i.e., sandy), or if a sand or gravel seam is located within this layer, the surface material should be temporarily removed and a compacted clay or fabricated liner installed. Once the liner is installed, the original material can be replaced.

Since the rooting depth in surface flow wetlands will typically be less than 12 inches (30 cm) and approximately 80 percent of the root mass for most emergent plants will be within the top 6 inches (15 cm) of soil, the top of the liner should be 12 to 15 in (30 to 38 cm) below the intended surface of the wetland. In other words, the soil/plant medium which overlies the liner should be at least 12 inches thick.

Whenever a liner is installed, care must be taken to ensure that it ties in vertically at the embankments, thus preventing lateral movement under the embankments.

Soil permeability should be evaluated in light of state restrictions on allowable seepage rates. A typical allowable permeability rate is 1×10^{-5} cm/sec (0.028 ft/day). The specific discharge is determined by use of Darcy's Law as given in the following equation and illustrated in Figure 3:

$$Q=k(h/d)A$$

where--

Q = discharge (seepage),(ft^3/d)
k = hydraulic conductivity (ft/d)
h = vertical distance between the maximum surface elevation of the overlying liquid and the bottom of the compacted soil liner (ft)
d = thickness of the soil liner (ft)
h/d = hydraulic gradient (ft/ft)
A = cross sectional area of flow (ft^2)

With terms rearranged:

$$Q/A = k(h/d) \quad \text{or}$$
$$v = k(h/d)$$
= specific discharge or seepage per unit area (distance/time).

The hydraulic head (h) is relatively small for constructed wetlands (usually less than 18 inches); therefore, the potential for seepage is expected to be minimal, assuming a moderately clayey soil is available or a well compacted clay liner is installed. However, at questionable sites (sandy soils, underlying limestone rock, etc.), a detailed evaluation of potential seepage should be conducted. The planner is advised to review information developed by NRCS on this topic, as needed (USDA, 1993).

The soils investigation will also determine if shallow bedrock is encountered. If bedrock

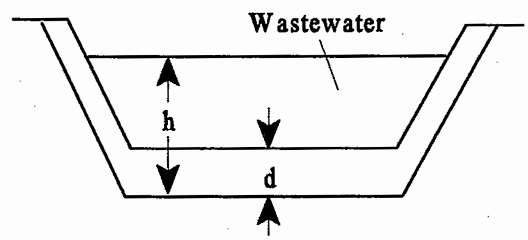


Figure 3. Relationship between h and d in determining thickness of liner

consists of easily solubilized limestone or if fractured sandstone is located close to the proposed bottom elevation of the wetland, a liner should be considered. The characteristics of the soil and soil depth should be carefully evaluated in this case.

2. Wastewater storage: Two types of storage should be considered during planning: (1) storage downstream of the wetland, used for recycling, irrigation, and, possibly, winter storage, and (2) winter storage in the pretreatment unit. If the wetland will not have a discharge, then a downstream storage pond is essential. If the wetland will not function during the dormant season, then wastewater must be stored during that period either in a downstream pond or in the upstream pretreatment unit. If the upstream unit is already in place but was not designed to accommodate the volume of wastewater needed for this system, it may be easier to build a downstream storage pond than to add additional storage to the pretreatment unit.

A water budget will be needed to determine the required capacity of the storage units whether upstream or downstream. See later discussion on *Hydrologic and Climatological Data* and on *Water Budget.*

3. Topography: The lay of the land has an important impact on the number of cells that may be needed and, hence, the overall cost of construction. All wetland cells should have level bottoms side-to-side and nearly level bottoms in the lengthwise direction. If the land has a considerable slope, it may be necessary to install several cells in order to maintain a relatively constant water depth. With each new cell a new embankment is needed which will occupy more room in the overall system.

The wetland should accommodate topography in such a way that, wherever possible, earthwork cuts and fills can be balanced during construction. A slight slope in the direction of the outlet end of each cell may be used to allow for complete drainage of the cell for maintenance. However, the same purpose can be achieved by installing a deep zone at the end of the cell which can be pumped to facilitate drainage. (See further discussion under *Bottom slopes/maximum length.*)

4. Land area: The wet area of the system, as determined by appropriate design equations, may be as little as half the total area required. (See following section entitled *Determining wetted surface area.*) If the land is sloping, additional cells and embankments will be needed. In most cases a storage pond will be placed downstream of the system to collect the wetland effluent for recycling and irrigation. This pond will need to be sized in accordance with the design requirements of the proposed irrigation system. If a discharge will be permitted, additional space may be needed for flow measuring weirs and a sample collection station.

5. Surface water: The proximity of the wetland to the nearest stream or waterbody should be noted in the waste management plan. The size and characteristics of the stream will be important factors if a discharge is planned. Any receiving stream must have the capacity to assimilate wastewaters discharged during low-flow periods. State regulatory agencies must determine if the stream has the necessary capacity to receive wastewaters from the wetland and provide the necessary information on permits.

6. Groundwater: The site evaluation must consider depth to groundwater and proximity of the system to nearby wells. Allowable distance to domestic wells will be specified by the state regulatory agency.

If any wells are in close proximity to the site, water samples should be collected prior to installation of the wetlands and be evaluated for fecal coliform and fecal streptococcus bacteria, nitrates (NO_3-N) and ammonia nitrogen (NH_4+NH_3-N). Without preconstruction sampling, there will be no evidence of pre-existing contamination if it is later found that the wells are contaminated.

If shallow ground water is noted, it is suggested that at least one monitoring well be installed down slope of the wetland or in an area selected by a professional geologist. State regulatory officials should be consulted if the seasonal high-water table of such ground water will be in close proximity to the bottom of the wetland.

7. Floodplains: Two important questions should be considered when planning the installation of a constructed wetland within a floodplain. First, will placement of the structure restrict flow to the extent that damage to upstream or cross-stream properties could occur? And, second, can the system be economically protected from a relatively severe level of flooding, such as the 50-year or 100-year, 24-hour storm? State regulatory agencies may require certain restrictions in this regard. In addition, Corps of Engineer requirements may come into play. Thus, both state and Federal regulatory requirements as well as the overall economic impact should be considered in designing to protect from some prescribed storm event.

8. Fencing: Fencing around the site may be required by state regulations, or it may be needed if grazing animals could gain access to the wetland. Cattle have been known to enter a wetland, destroy vegetation and damage embankments. Adding fencing will add to the cost, but it will be essential in some cases.

9. Jurisdictional wetlands: The site being considered for a constructed wetland should not be in a jurisdictional wetland. A professional opinion is essential if there is any doubt about the location.

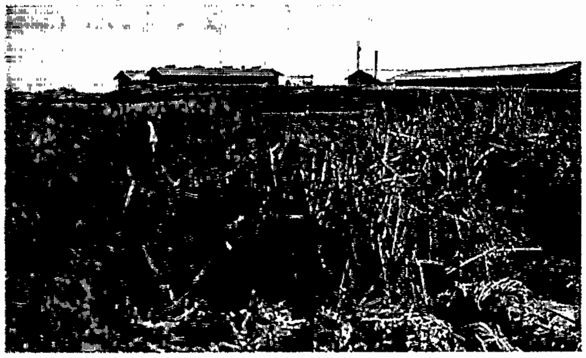
10. Sociological factors: How will neighbors react to the wetland? Since the animal feeding facility and waste treatment facility may already be in place, the addition of the wetland should not be a problem; rather, it should be viewed as a benefit. However, distance to neighbors should be considered in light of possible concerns about the type of wildlife that might be attracted to the wetland.

□ Hydrologic and climatologic data

Monthly data on precipitation, pan evaporation, and temperature are essential for design and must be gathered during planning. The rainfall and evaporation data provide information needed to determine hydraulic retention time in the wetland, the size of winter storage (if used) in the pretreatment unit (lagoon, storage pond, etc.), and the overall monthly water budget, which is especially important where land application is used after wetlands treatment. The volume of precipitation water produced each month includes that which falls directly on the pretreatment unit and wetlands, including embankments; and runoff from roofs, open lots, and other areas draining into the system. This information is combined with data on manure and flush water volumes to determine initial volume input to the system.

Evaporation is deducted from the precipitation input on open pretreatment structures. This amount will be equivalent to lake evaporation which is considered to be 70 to 80 percent of monthly pan evaporation. In addition, evapotranspiration within the wetland is also considered to be roughly equivalent to lake evaporation.

Temperature data are used in equations to size the wetland. If the wetland is being designed for a discharge, the average monthly ambient temperature for the coldest period should be used for water temperature. If the monthly average is below zero degrees C and wastewater will be treated beneath an ice cover, special precautions and design considerations are necessary. Water level must be raised to a depth equivalent to the thickness of the anticipated ice cover plus the expected depth of flow during the winter. Following freezing, water level is lowered to allow water flow under the ice. The embankment height must be sized accordingly.



Treatment continues in the wetland even in winter but at a slower rate.

In northern climates where long periods of freezing weather can be expected, vegetation, ice cover, and snow can provide an insulating effect for the water. Assuming water continues to flow throughout the period of ice cover, a design temperature of 35 - 39° F (2 - 4° C) would provide a conservative design.

It should be noted that detailed guidance on calculating temperatures can be found in various literature (Kadlec and Knight, 1996; Reed et. al, 1996). These take into account such factors as temperature of the incoming water, the length of the wetland, and open areas. For large livestock facilities with high volume and year-round flows in cold climates, these resources should be consulted for design of livestock wetlands. Otherwise, the design guidance provided in this publication will be adequate.

RECOMMENDATION: Despite the fact that design guidance for constructed wetlands is available for cold weather systems, it is recommended that wastewater from livestock operations be stored in a lagoon or waste storage pond during the cold months, not only in northern climates, but also in all areas where (a) land application will be the preferred mode of operation versus discharge and (b) vegetation at the land application site will be dormant in winter. In the case of discharge systems, this strategy will eliminate the possibility of failure of a wetland designed for winter treatment. For nutrient matching (land application) systems, this strategy will reduce wetland size, eliminate operation and maintenance problems throughout the winter, and, generally, provide for ease of management.

If wastewater is stored during the winter months and released to the wetland only during the warmer season, *and if a discharge is planned*, the average monthly temperature for the coldest month during the period of discharge is used in design. However, if wastewater is released to the wetland during only the warm season *and if the wetland is designed to reduce nutrients to a specific level for land application (nutrient matching)*, then the average temperature over all months of the warm season should be used in design.

In cold climates knowledge of monthly temperature data also allows the planner to advise the user of the date that the water level should be raised in anticipation of the onset of freezing weather (assuming a winter discharge is planned) or the date that wastewater to the wetland should be discontinued.

☐ Regulatory requirements

State water quality regulators will determine if the wetland can be permitted for discharge under NPDES, state, or water conservation district requirements. If permitting is allowed and will be part of the system design, the owner must be fully aware of all monitoring requirements and the costs of obtaining and maintaining the necessary permits. If the system is not allowed to discharge, the owner must plan on having a storage pond to collect the wetland effluent for irrigation and/or recycling as flush water. In this case, the owner must manage the system to prevent overflow and, thereby, avoid violating regulations.

The planner should be familiar with other regulations regarding natural or jurisdictional wetlands, odor control, and setback distances from property lines, neighbors' houses, wells, streams, roads, public areas, and other areas that may be governed by regulation.

Design of SF Wetlands for Livestock Wastes

It should be noted that design of surface flow constructed wetlands for livestock waste treatment is not an exact science. Likewise, the methods for determining pollutant reductions in animal waste lagoons or in predicting wastewater nutrients available for land application are based only on reasonable estimates. Thus, the information presented here provides the best available technology based on research findings and allows the designer to appropriately size a wetland to meet, within reasonable limits of expectation, the treatment goals.

☐ Determining wetted surface area

1. *Methods available for sizing:* In 1991, the USDA-NRCS (formerly the SCS) published its Technical Requirements on constructed wetlands for treating agricultural wastes (USDA-NRCS, 1991). This document, entitled "Constructed Wetlands for Agricultural Wastewater Treatment" (CWAWT) was based on state-of-the-art information at that time and has been the principal design document for livestock constructed wetlands since then.

It should be noted that the design of constructed wetlands for livestock waste treatment is not an exact science.

The CWAWT document provides two methods for design: the *Presumptive Method* and the *Field Test Method.* The Presumptive Method uses information developed by the Tennessee Valley Authority (USDA-NRCS, 1991) and the Field Test Method uses equations developed by Reed et al.(1988). More recently, Kadlec and Knight (1996) have developed a slightly different equation that can be used to size livestock constructed wetlands; this is also a field test method, meaning samples must be collected from the pretreatment unit for use in the equations. Each of these methods will be described and compared.

The methods presented by NRCS have as their goal treatment levels that meet or exceed NPDES discharge requirements. When NRCS initially prepared their Technical Requirement on constructed wetlands, they did so knowing that little information was available on this type system for animal wastes. Thus, they set treatment goals related to discharge limits for BOD_5, TSS and NH_4-N to standardize design procedures and to allow the agency to have a basis for comparing the results from one system to another. The establishment of concentrations at or below the typical NPDES discharge limits was not intended to promote the discharge of wastewater but, rather, to serve as a benchmark and to promote consistency in design throughout the country.

The NRCS guidance did indicate that effluent could be discharged *only* if appropriate federal, state, and local permit requirements were satisfied. Otherwise, the wetland effluent must be collected in a storage pond and held until it could be land applied or recycled. No thought was given at that time to determining the total nutrient load desired at the final land application site, then sizing the wetland so that nutrient levels could be reduced just enough to meet the needs on the land (nutrient matching). Only after a number of systems were installed and data gathered did it become apparent that design could be based on nutrient needs at the land application site and not necessarily on discharge limits (Payne et al., 1996). Using the wetland for nutrient matching is discussed in the following sections.

a. *Presumptive Method*: This method represents one of the original NRCS design approaches. It is used where data on the wastewater characteristics of the lagoon or other pretreatment unit are not available. In this case, the designer makes estimates (presumptions) about the amount of BOD_5 or nutrients produced by the animals and the amounts lost in the selected pretreatment unit. Information is derived from tables such as those presented in the NRCS AWMFH (USDA-NRCS, 1992). The wetland is then sized on the basis of 65 lb BOD/ac/d (73 kg BOD/ha/d). The goal in this method is to reduce BOD_5 concentrations to less than 30 mg/L, the anticipated allowable discharge concentration. As noted, the NRCS was not proposing discharges from the wetland but was using current design technology during the initial trials on animal waste constructed wetlands. That technology, based on municipal systems, sought treatment levels below the allowable thresholds for discharge.

If this approach were used to design a wetland for treating the lagoon discharge from a 2,000 head swine facility, the designer might use the following data:

BOD Produced: 2.08 lb BOD/d/1000 lb of animal (Appendix C)

Avg. animal wgt: 180 lb/hd for finishers

% BOD remaining after treatment: 25% (recommended in original requirements for a warm climate; USDA-NRCS, 1991)

Areal loading for wetland sizing: 65 lb/ac/d

The wetland size required to meet or exceed the 30 mg/L wetland discharge guidance would be calculated as follows:

(1) BOD available after treatment:

(2,000 hd.)(180 lb/hd)(2.08 lb. BOD/1,000 lb)(0.25)

= 187 lb BOD/d

(2) Wetland size:

(187 lb BOD/d)/(65 lb BOD/ac/d) = 2.9 ac

After the initial sizing, it is necessary, according to the original guidelines, to check the hydraulic residence time in the wetland to ensure that it is at least 12 days. The equation is follows:

$t_d = (SA)(d)(p)/Q$

where--

t_d = hydraulic retention time (days)

SA = surface area of the wetland (ft^2)

d = avg. water depth in the wetland (ft)

p = porosity, a figure which accounts for the volume not occupied by the plants (i.e., 0.9 for cattails).

Q = flow rate (ft^3/day)

It has since been found that hydraulic retention time (HRT) is a function of decay rate constants for specific pollutants. In other words, the rate constants for phosphorus, BOD, and total nitrogen would be different and, hence, the detention times to meet specific discharge limits for these constituents would be different. Thus, the all purpose 12-day value used earlier is not valid based on new information.

In addition, a recent review of actual data from livestock wastewater constructed wetlands (CH2M Hill and Payne Engineering, 1997) indicates that the presumptive method is overly optimistic in predicting outflow concentrations for many systems. Based on the review of published treatment wetland data from a variety of livestock wastewater management systems throughout North America, at a presumed loading of 65 lb BOD/ac/d, the average effluent BOD concentration (that expected to be achieved 50 percent of the time) is about 70 mg/L. A loading of less than about 9 lb BOD/ac/d (10.1 kg/ha/d) would be necessary to meet the 30 mg/L goal about 80 percent of the time.

The work of McCaskey and Hannah (Section II, Case Histories) confirm this finding. Based on more than five years of research on a constructed wetland for swine lagoon effluent, they suggest that the loading rates required by the presumptive method are greatly overstated. They contend that a BOD loading rate of 5.9 lb/ac/d is needed to meet effluent discharge requirements most of the time; however, in the winter months the regulatory limits could not be met even at these low loading rates.

Table 4 provides expected outflow concentrations for certain pollutants based on estimated hydraulic loading rates (HLR). This table has been presented by CH2M Hill

(1997) and reflects an analysis of data from actual livestock treatment wetlands (Knight et al., 1996).

Table 5 summarizes treatment performance for the various constructed wetlands reported in the LWDB (Knight et al., 1996), which is based on wetland systems for dairy, beef cattle, swine, poultry, and aquacultural sites located throughout North America. Only the major constituents are reported in this table.

Most of the systems identified in the LWDB (Knight et al., 1996) were designed using the presumptive method. It has been found that, in some cases, where low outflow concentrations were regularly obtained, actual loading rates were much less than the 65 lb BOD/ac/d recommended in the original presumptive design method. Based on this information and on the data shown in Tables 4 and 5, it is evident that the original assumptions used in the presumptive method need to be modified in order to achieve the desired outflow concentrations.

Table 4. Estimated pollutant loadings to achieve desired outflow concentrations 80 percent of the time.

Pollutant	Desired Wetland Outflow Concentration (mg/L)				
	20	30	50	100	200
	Estimated pollutant loadings (lb/ac/d)				
BOD_5	5.5	9.0	18	39	80
TSS	6.0	11.0	27	71	180
TN	3.0	6.0	10	26	53
TP	2.5	6.0	10	26	53

Table 5 . Summary of average performance of animal wastewater treatment wetlands.*

Wastewater Constituent	Inflow Conc. (mg/L)	Outflow Conc. (mg/L)	Avg. Reduction (%)
BOD_5	263	93	65
TSS	585	273	53
NH_3+ NH_4-N	122	64	48
TN	254	148	42
TP	24	14	42

*Source: CH2M Hill (1997), as summarized from Knight et al. (1996).

For the reasons indicated above, it is recommended that the design guidance for the original *Presumptive Method* not be used. It should be noted that the original NRCS guidance document (USDA, 1991) cautioned that neither of the methods which they presented had been thoroughly evaluated for animal wastes systems over an extended period of time and at a variety of locations. It stated that "these methods are considered state of the art and will likely be modified and refined as additional systems are installed and monitored as part of the demonstrations associated with these technical requirements."

Now, indeed, additional information is available to allow modification of the original design guidance, both for the *Presumptive Method* and for the *NRCS Field Test Method*. In this regard, a *Modified*

Presumptive Method is provided in the following section based on more recently acquired data.

b. *Modified Presumptive (MP) Method*

Unlike the original presumptive method which uses hydraulic retention time (HRT) as a check, the Modified Presumptive Method takes into account pollutant mass loading or volume of water applied and relates the results to a data table derived from an analysis of information gathered from actual animal waste constructed wetlands.

Table 6. Estimated pollutant loadings to achieve desired wetland outflow concentrations 50 percent of the time.

Pollutants	Desired Wetland Outflow Conc. (mg/L)			
	20	30	50	100
	Estimated Pollutant Loadings (lb/ac/d)			
BOD_5	18	29	45	89
TSS	13	27	54	120
TN	6.7	9.1	24	54
TP	10	16	25	50

If a discharge is anticipated, the more stringent loading rates in Table 4 should be used. However, due consideration should be given to the fact that discharge limits could be exceeded at certain times.

If the system will be designed for nutrient matching (see *The value of constructed wetlands)*, loading rates to achieve desired outflow concentrations 50 percent of the time are recommended. Table 6, based on data from numerous livestock constructed wetlands, provides the estimated loading rates required to achieve this level of treatment for several constituents. Thus, at a given loading rate, the effluent concentration shown in the table will represent the average expected on an annual basis. Approximately half the concentrations will be above the listed value and half will be below. For the nutrient matching approach, where treated wastewater is collected and land applied, some variation in nutrient application rates is acceptable for most cropping systems; in fact, it is normal.

Based on this information, the Modified Presumptive Method is presented here in the form of an example. It is assumed that the wetland effluent will be collected and then land applied. In this case, Table 6 will be essential for wetland sizing.

Given:

2,000 finishing swine
Average weight: 180 lb.
Pretreatment of wastewater in an anaerobic lagoon:

- surface dimensions of 400 x 400 ft.
- 20 percent of original as-excreted N is available in lagoon effluent
- No surface runoff into the lagoon

Annual precipitation: 45 in
Annual evaporation: 38 in
Crop N required: 150 lb N/ac/yr
Land available at application site: 40 ac
Wetland effluent stored in downstream storage pond for 60 days between irrigations.
Wastewater recycled during winter months.

Determine size of constructed wetland to match nutrient requirements on 40 acres:

Step 1: Determine total N per day and per year after treatment losses:

a. As-excreted N:

(No. Animals)(Avg. Wt.)(N /d/1000 lb. animal)

= lb N / day

(2,000 finishers) (180 lb/hd) (0.42 lb N/d/1,000 lbs)

= 151 Lbs N/day

b. Daily N in lagoon effluent after losses:

(151 lb. N/day) (0.2) = 30.2 lb. N/day in lagoon effluent

c. Multiply answer from Step 1b by 365 to find average annual N:

30.2 lbs/N/day x 365 days/yr = 11,023 lbs N/yr

Step 2: Determine land area required if pumping directly from lagoon:

$$Ac. = \frac{N/yr\ available\ after\ trmt.\ [Step 1]}{crop\ N/ac/yr\ rqd.}$$

$$\frac{11{,}203\ lb N/yr}{150\ lb N/ac/yr} = 73.5\ ac$$

Thus, the land available (40 ac) is less than that required (73.5).

Step 3: Determine average N required per year on the available acres:

(Acres available) (application rate)= annual N rqd.

(40 ac) (150 lb/ac/yr) = 6,000 lb N/yr required (net)

Step 4: Determine desired average daily N required in the wetland effluent to satisfy the irrigated crop N required:

NOTE: If wetland effluent will be stored for more than 45 days between irrigations, assume that 10 percent of the N will be lost. Therefore, increase the net N required (Step 3) by 10 percent to determine the gross (before storage losses) N desired in the wetland effluent:

$$\frac{(N/yr: Step 3)(loss\ adjustment)}{365\ d/yr)} = (N/day\ rqd.)$$

$$\frac{(6{,}000)(1.1)}{(365)} = 18.1\ lb N/d$$

Step 5: Determine volume of water produced per day and per year

a. Flush water:

(Number of animals) (Flush volume/head [app. C])

= daily flush volume

(2,000 hd.)(15 gal/hd/day) = 30,000 gpd

b. Volume of animal waste (displacement of lagoon water):

$$(No.hd)(180\ lb/hd)(7.48\ gal/cf)\frac{(manure\ vol)}{(1{,}000\ lb\ animal\ wgt)}$$

=(2,000 head)(180 lbs) (7.48 gal/cf)(1.0 cf/1,000 lb)

= 2,693 gpd

c. Precipitation minus evaporation on lagoon surface:

$$\frac{(L)(w)(precip.-evap.)(7.48\ gal/cf)}{(12\ in/ft)(365\ d/yr))}$$

$$= rain\ volume\ (gal/d)$$

$$\frac{(400\ ft)(400\ ft)(45-38\ in/yr)(7.48\ gal/cf)}{(12\ in/ft)(365\ d/yr)}$$

$$= 1{,}913\ gal/d\ avg.$$

d. Total average volume of water per day: Items a + b + c = total gal/day

$$(30{,}000\ gal) + (2{,}693\ gal) + (1{,}913\ gal)$$

$$= 34{,}606\ gal/day\ average$$

Step 6: Apply average daily N in the wetland effluent (lb/day) in Step 4 to average daily water volume (gal/day) in Step 5d, together with a conversion factor, to find desired average N concentration for the constructed wetland effluent.

$$\frac{(18.1\ lb.\ N/d)(119{,}404)}{(34{,}606)}$$

$$\frac{(Avg.\ daily N)(119{,}904)}{(avg.\ daily\ water\ vol.)} = N conc.\ (mg/L)$$

$$= 62.7\ mglL\ N\ (avg.\ daily)$$

Step 7: Apply result of Step 6 to Table 6 to determine the estimated pollutant loading rate to the constructed wetland.

Note that 62.7 mg/L is between 50 and 100 mg/L for the Desired Wetland Outflow Concentration in the table; consequently, the estimated pollutant loading rate will be between 54 and 24 (lb/ac/d). Extrapolate between 50 and 100 as follows:

$$\frac{(62.7-50)}{(100-50)}(54-24) = 31.6\ lb/ac/d$$

Step 8: Divide the average daily lagoon effluent N (Step lb) by the estimated loading rate (Step 7) to find the estimated area of the constructed wetland:

$$Surface\ area\ of\ wetland = \frac{(Step\ 1b)}{(Step\ 7)}$$

$$\frac{(30.2\ lb N/d)}{(31.6\ lb N/ac/d)} = 1.0\ ac$$

b. Field Test Method #1: The original equations presented by Reed et al. (1988) and used by NRCS allowed the user to first solve for t_d and then insert this value into the equation for determining the wetland surface area. This method was state of the art at the time NRCS adopted it for use in designing agricultural waste treatment wetlands.

The area equation has been updated (Reed et al., 1995), and only this new equation is presented here. Thus, the equation for area of the wetland is:

$$A = Q\frac{(\ln C_i - C_e)}{(K_T)(d)(n)}$$

where--

A = surface area of the constructed wetland (m^2)
Q = average flow through the

wetland (m^3/d)
C_i = influent concentration (mg/L)
C_e = effluent concentration (mg/L)
k_T= temperature dependent, first order rate constant (d^{-1})
= $k_{20}\theta^{T-20}$, rate constant adjusted for temperatures other than 20°C.
(k_{NH} = 0.2187 @ 20° C; θ = 1.048)
d = design depth of water in the system (m); typically 0.1 - 0.46 depending on season and water quality expectations
n = "porosity" of the wetland (0.65 0.75)

The porosity factor in this equation accounts for the space occupied by plant stems and litter within the water column. According to Reed et al., 25 to 35 percent of the water column is filled by plant stems and litter. Watson and Hobson (1989) reported fill rates of 10% for cattails (*Typha*), 14% for bulrush (*Scirpus validus)*, 2% for reeds (*Phragmites*), 6% for woolgrass (*S. cyperinus*), and 5% for rushes (*Juncus*). Rogers (1995), based on field measurements, reported rates of 10% for *Sagittaria lancifolia* and 7% for *Phragmites australis.* However, it is necessary to use the values prescribed by the originators of the Method#1 equation in order to achieve the proper results for that model.

The value for Q is the average of inflow (Q_i) and outflow (Q_e). Since the total evaporative loss for the wetland cannot be determined until the wetland surface area is known, Q cannot be initially known. The authors of Method #1 suggest letting $Q_i = Q_e$ for initial design, but final system design should be adjusted to account for all losses.

c. Field Test Method #2: The equation for this approach is as follows:

$$A = -(Q/k_T)\ln\left[\frac{(C_e - C^*)}{(C_i - C^*)}\right]$$

where-

A = area of the constructed wetland (m^2)
Q = annual flow (m^3/yr)
k_T= $k_{20}\theta^{T-20}$, rate constant adjusted for temperatures other than 20° C (m/yr)
k_{20} = 14 for TN and 10 for NH_3-N (m/yr)
θ = 1.06 for TN and 1.05 for NH_3 (dimensionless).
C_i= inflow concentration (mg/L)
C_e= outflow concentration (mg/L)
C^* = background concentration (mg/L), assumed to be 3 for ammonia and 10 for TKN.

The equation was described initially for treatment wetlands by Kadlec and Knight (1996), and rate constants specific to concentrated animal wastes were summarized by CH2M Hill and Payne Engineering (1997). Several rate constants, recommended for use in the k-C^* model of Method #2, are shown in Table 7.

Water depth and hydraulic retention time are not factored into the equation, but it is assumed that water depth is sufficient to cover all roots and rhizomes and that HRT will be sufficient to provide the necessary contact time for biological degradation of pollutants. (See *The role of emergent*

Table 7. Parameter values recommended for use in the k-C^* model for sizing animal waste treatment wetlands[*]

Parameter	k_{20} (m/yr)	C^* (mg/L)	θ
BOD_5	22	8	1.03
TSS	21	20	1.01
$NH_3 + NH_4$-N	10	3	1.05
Total N	14	10	1.06
Total P	8	2	1.05

[*] These values are preliminary and may be revised as additional data analyses are completed.

herbaceous plants in the treatment process under *Vegetation* above.) Data analysis from non-agricultural treatment wetlands indicates that increasing water depth does not result in a proportional increase of treatment performance (Kadlec and Knight, 1996).

HRT does affect contact time between wastewater and bacterial communities and HRT does, in fact, have an influence on treatment efficiency. A study at the Sand Mountain project illustrated that as flow rate was increased in one set of cells, effluent concentrations of most pollutants more than doubled (Payne et al., 1992). In other cells flow rate was reduced and treatment efficiency increased. In this study, contact time was increased or decreased by simply increasing or decreasing inflow rate into the cells and not by increasing or decreasing water depth.

2. Comparing methods:

Where actual data on pollutant concentrations are not available for a given site and an estimate of wetland size is needed, the planner may use the Modified Presumptive Method. However, it should be understood that the estimates or "presumptions" that are made with this method can result in considerable variation in the overall size.

In the example shown under the Modified Presumptive (MP) Method, two assumptions were made: (1) that the average animal weight was 180 lb and (2) that the fraction of N remaining after lagoon treatment was 20%. If another designer chose 150 lb as the average weight and assumed only 10% of N remaining, the wetland size would be reduced from 1.0 to 0.3 ac. Table 8 illustrates the differences in wetland sizes using 150 and 180 lb average weights and 10 and 20 percent remaining N.

Table 8. Wetland sizes using the MP Method for 2,000 top hogs with different estimated average weights and N remaining after pre-treatment

Avg. Wgt.	% N remaining	Wetland area	
		(ac)	(m^2)
150	10	0.3	1,215
150	20	0.8	3,239
180	10	0.5	2,024
180	20	1.0	1,048

It might be noted that the value selected for N remaining could be a function of climate just as BOD remaining is assumed to be (USDA-NRCS, 1991). In other words, only 10 percent of the original N might be remaining in warm climates, whereas 20 percent could be available in cooler climates.

The planner is advised to use the modified presumptive approach with caution. The final result should be a good approximation for planning purposes. However, the use of this approach, like the one that preceded it, should be evaluated over time and adjusted as needed.

One of the Field Test Methods should ultimately be used wherever possible. If the animal confinement facility is not yet installed, this may mean collecting samples from the pretreatment unit of an identically operated facility with a nearly identical pretreatment unit and using that information in the field test equations for the new facility. Another option would to postpone construction of the wetland until samples can be collected from the pretreatment unit of the system for which the wetland will be used.

A comparison of the two field test methods was made, using an example involving a 2,000-head swine finishing or top hog operation. It is assumed that samples were collected from an existing facility to help design a waste managment system at a new site. The would-be producer finds that he has too little land for direct irrigation based on information from the existing facility. If the wastewater in the new lagoon were pumped directly to the land, 73.6 ac (29.8 ha) would be needed to satisfy the nitrogen requirement of a particular crop; however, only 40 ac (16.2 ha) is available.

Using the nutrient matching approach, the designer seeks to use a constructed wetland to reduce the nitrogen level to 54 percent of the original amount (40 / 73.6) so the wastewater can be applied to the 40 available acres. Based on data from the existing lagoon, the nitrogen concentration in the supernatant of the new lagoon is expected to be 200 mg/L. This must be reduced to 108 mg/L or 54% of the original amount. *Daily* flow rate (Q) for Field Test Method #1 is 130 m^3/d. Q for Method #2 is an *annual* amount and is 47,450 m^3/yr or 365 times the daily average value used in Method #1.

The lagoon supernatant contains no NO_3 and ammonia constitutes 80 percent of TKN. Table 9 illustrates the differences in wetland size for given conditions of temperature (T), porosity (n), and water depth (d). All metric units have been used in this example.

Although Reed et al. (Method #1) suggest using porosity values of 0.65 to 0.75, other recent studies, noted above, indicate that porosities in the range of 0.85 to 0.95 are appropriate for the most popular plants that would be used in wetlands for animal waste treatment. However, in order for the equation to provide the results achieved by the model for certain municipal situations, the developer's porosity value of 0.75 was used in the comparison. Three values for water depth have been used: 8 in (0.203 m), 10 in (0.2554 m), and 15 in (0.381 m).

It is noted that as water depth increases in Method #1, wetland surface area decreases and, in turn, the sites for microbial activity also decrease. If Method #1continues to be used for design, it would appear best to initially minimize average depth in order to maximize surface area and the sites where most microbial activity will occur. That is, water depth should be just high enough to cover roots, rhizomes and plant litter.

Table 9. Comparison of constructed wetland surface areas using Method #1 and Method #2 for ammonia concentrations of C_i = 200 mg/L and C_o = 108 mg/L.

T(°C)	Area (m^2); Method #1 for n = 0.75 water depth (d_{av})			Area (m^2) Method #2
	0.203m	0.245m	0.381m	
10	3840	3182	2046	5150
15	3041	2520	1620	4028
20	2402	1991	1280	3141
25	1906	1579	1016	2454
30	1503	1246	801	1927

It would appear that treatment performance could be improved by simply raising the water level and, thereby, increasing the time of contact between the wastewater and the microorganisms. While some increase in efficiency may be obtained in this manner, current data on animal waste treatment wetlands indicate that increasing water depth will not result in a proportional increase in treatment. In addition, data on municipal systems (Kadlec and Knight, 1996) suggest that the rate constants of Method #1 would have to be reduced as water depth is changed in order to get accurate results for animal waste systems.

The general equations for both Methods #1 and #2 were developed for municipal systems. However, the rate constants (k_T and k_{20}) and theta values (θ) applicable to Method #2 were derived from the current livestock wetlands database (CH_2M Hill and Payne Engineering, 1997). This method assumes that treatment performance is directly proportional to wetland surface area and that increasing depth does not provide a proportional increase in performance. Thus, sizing for ammonia reductions based on Method #2 provides a larger surface area than Method #1 for all temperatures evaluated as shown in Table 9.

3. Selecting a method (recommendations):

The planner should fully understand that current wetland design criteria for animal waste systems will provide a reasonable prediction of treatment performance but that predicted values may still be somewhat different than actual values. If a wastewater discharge is being considered, the most conservative approach to design should be used. If wastewater will be land applied after treatment, the concern over reaching presribed treatment levels all of the time is much less critical. With these thoughts in mind, the following recommendations for designing animal waste constructed wetlands are provided:

(1) If adequate information on average daily flow rates and effluent concentrations of selected constituents from the pretreatment unit are not available for the system, the

Modified Presumptive Method can be used to estimate wetland size. However, due consideration should be given to the cautions noted above when using any presumptive method. If a discharge is anticipated, a field test method should be used for final design.

(2) When using a field test method, it is recommended that Method #2 be used because:

(a) it is based on current livestock data, and

(b) it provides a slightly larger surface area, which adds a measure of safety

(3) When sizing for nutrient matching of nitrogen, data for ammonia nitrogen should be used rather than total nitrogen. Ammonia nitrogen typically represents 70 to 80 percent of the total nitrogen for most animal waste pretreatment units. Some of the TN in the wetland effluent will be lost during storage and some during land application. Therefore, the organic fraction (20 to 30 percent of TN), which will convert to ammonia, is expected to approximately balance that which is lost during downstream storage and application. In addition, using the given values of k and θ for TN without considering conversions will result in a smaller wetland.

(4) If the wetland will have an approved discharge, it is recommended that the size be increased by 20 percent beyond that recommended by the equation. It should be noted that there will be variability around the predicted outflow concentrations, regardless of which equation is used. In other words, the equations provide sizes that will ensure treatment to at least the predicted concentrations about 50 percent of the time; consequently, increasing the size will add a margin of safety.

(5) Dormant season storage of wastewater and subsequent land application based on nutrient matching is recommended over discharge. This approach will allow for the use of average warm season temperatures in design, which will, in turn, reduce the size of the wetland. It will also prevent the problems associated with the permitting process and with monitoring.

(6) If a discharge is being considered, it is recommended that the designer refer to the more detailed information provided by the sources mentioned in this publication.

□ Bottom slope/maximum length

The earlier design guidance by NRCS indicated that a slope in the lengthwise direction of the wetland would facilitate drainage in case repairs or maintenance were needed. Indeed, a slope can be built into the wetland to accomplish this purpose; however, due consideration should be given to the rapid increase in depth that will occur if the slope is even as flat as 0.5 percent, the maximum value first recommended by NRCS. For instance, if the initial water depth at the upper end of a wetland cell is expected to be 6 inches (15.2 cm), the water depth at 100 ft (30.5 m) from the inlet would be 12 in (30.5 cm), and at 150 ft (45.7 m) it would be 15 inches (38 cm).

An acceptable alternative to this approach is to have a flat bottom with a deep zone across the downstream end. If the system must be drained, the water can be pumped from the deep zones to the land, to the downstream holding pond, or to the upstream pretreatment unit. The depth of the deep zones should be at least 3 ft (0.9 m) deeper than the marsh. (See Figure 4.)

If a sloping wetland is used, either by choice or by necessity resulting from site conditions, the maximum length is dependent on the allowable water depth associated with the wetland plants involved. If a level-bottom wetland is used, maximum length is not important for most animal waste treatment wetlands. If however, an exceptionally long, level-bottom wetland is planned, intermediate deep zones should be used, not only to facilitate drainage, but also to allow effective redistribution of flow.

□ Hydraulic retention time

The original NRCS guidelines required a minimum HRT of 12 days for livestock constructed wetlands. This was thought to be the time necessary to achieve the desired treatment levels for BOD_5 and ammonia.

Given the additional new data on animal waste wetlands, it has been found that HRT values needed to achieve recommended discharge limits could be higher or lower than 12 days depending on the constituent involved.

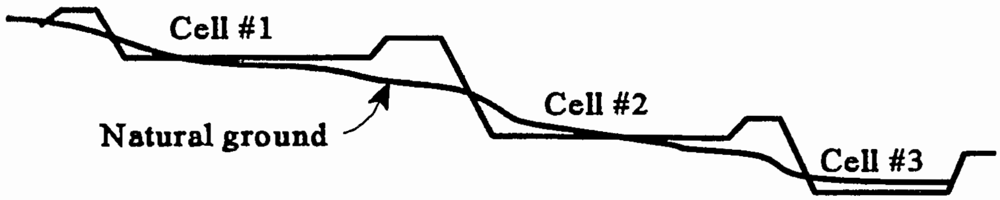
However, it should be noted that accurately estimating HRT is not a simple matter. In this process it is necessary to determine the as-built conditions in terms of bottom elevations, slopes of bottom and sides, width, and length. The designer must also know the average water depth, the average flow rate, and the volume of the water column not occupied by plants (porosity). Considerable error can be introduced into any estimation of HRT by changes in as-built conditions due to soil swelling, erosion of embankments and sedimentation; the uncertainty of actual porosity (see former discussion under *Field Test Method #1*); possible short circuiting due to uneven plant development; the shallow depths involved; and fluctuations in inflow rates.

There is no doubt that HRT affects treatment performance. Therefore, if a discharge is planned, the designer should still develop an estimate of HRT, giving due consideration to the possible inaccuracies that may be involved. This may mean using conservative values in making the estimates.

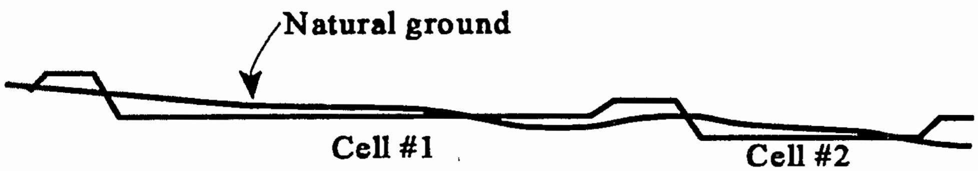
After the system has been installed, the HRT should be checked using lithium or another inert tracer to more accurately evaluate HRT and to allow for adjustments in flow.

□ Hydraulic loading rate

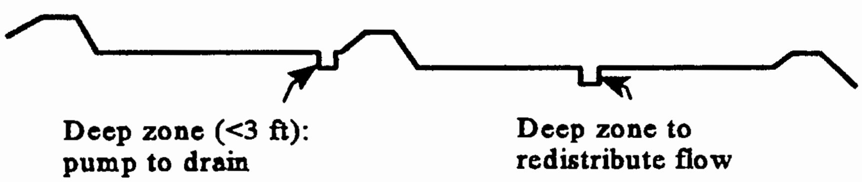
The hydraulic loading rate (HLR) is defined as the inlet wastewater flow divided by the wetland area, excluding embankments and islands. It is typically reported in units of in/d or ft/yr (cm/d or m/yr). HLR does not imply that the water is physically distributed uniformly over the surface area of the treatment wetland. HLR is generally easier to estimate than HRT, and it correlates more closely with treatment performance because of the reliance of most wetland processes on surface area rather than on water depth. CH2M Hill and Payne Engineering (1997) reported an average HLR of 1.85 in/d for treatment wetlands in the Livestock Wastewater Treatment Wetland Database. Table 5 summarizes the average constituent outflow concentrations and reduction efficiencies for those systems. Lower HLRs are necessary to achieve lower pollutant



4a. Steep sloping land: several cells needed to maintain level bottom



4b. Moderately sloping land: fewer cells needed for level bottom



4c. Cells with level bottoms and deep zones

Figure 4: Effects of Topography and the Use of Deep Zones

outflow concentrations from animal waste treatment wetlands.

□ Layout of the wetland

The layout of the system is sometimes dictated by site conditions. Shape of the site, area available, and lay of the land could be major constraints.

SF wetlands are often multi-cell systems. Cells will typically be arranged in series, depending on topography, and in parallel (side-by-side). The parallel arrangement allows two or more cells to receive effluent at the same time; thus, if the inlet structure in one cell plugs, the other cell(s) will keep operating. In addition, the parallel arrangement allows one set of cells to be closed for maintenance while the others remain operational. The owner can also use the parallel arrangement to rotate discharge points or to use different treatment strategies. (See Figure 5.)

An efficiently designed system will have limited short-circuiting of wastewater between inlets and outlets. In such a system, the waste flow will have continuous contact with all submerged surfaces most of the time. A large, square single-celled system with one inlet and one outlet would have dead areas in the corners unless flow is evenly distributed across the upper end. There will, of course, be some dead zones in nearly all systems caused by islands of roots, rhizomes, and dead vegetation. However, the goal is to provide flow across the entire width of each cell as practically as possible.

Barring any significant site constraints, the length-to-width ratio of the overall wetted area of the system should be in the range of 1:1 to 4:1. Ratios of individual cells have been as high as 20:1. Early designers of wetlands encouraged a ratio of 10:1 to ensure plug flow through the system. It was found, however, that the longer the cells, the greater the resistance to flow due to vegetation, especially at densely vegetated sites. At one municipal site having an aspect ratio of 20:1, the flow was so restricted that wastewater overflowed the embankment at the inlet end of the system (Reed et al., 1995).

Proper L:W ratios may help prevent short-circuiting of flows. Short-circuiting can also be minimized by initially distributing flow across the entire width of the first cell and subsequently redistributing the flow. Flow redistribution can be accomplished by adding cells in series and discharging the wastewater into each new cell through a distribution header pipe, or with an inlet deep zone across the width of the cell. Adding cells in series is a practice that may be necessary whenever a cell has a bottom slope for drainage or where the site itself is sloping.

Flow can be redistributed by constructing deep, narrow channels across the direction of flow. These deep zones can be placed at mid-length or more often for very long cells. Channels should be at least one meter deeper than the constructed bottom of the wetland cell to inhibit the growth of rooted vegetation (Kadlec and Knight, 1996).

□ Embankments

1. Design height: Although embankments at most livestock wetland sites are usually all the same height, a distinction can be made between the outer embankments and those which divide the system into cells. The outer

Cross-sectional and plan views of Lagoon/Wetland/Pond system with recycling and irrigation options

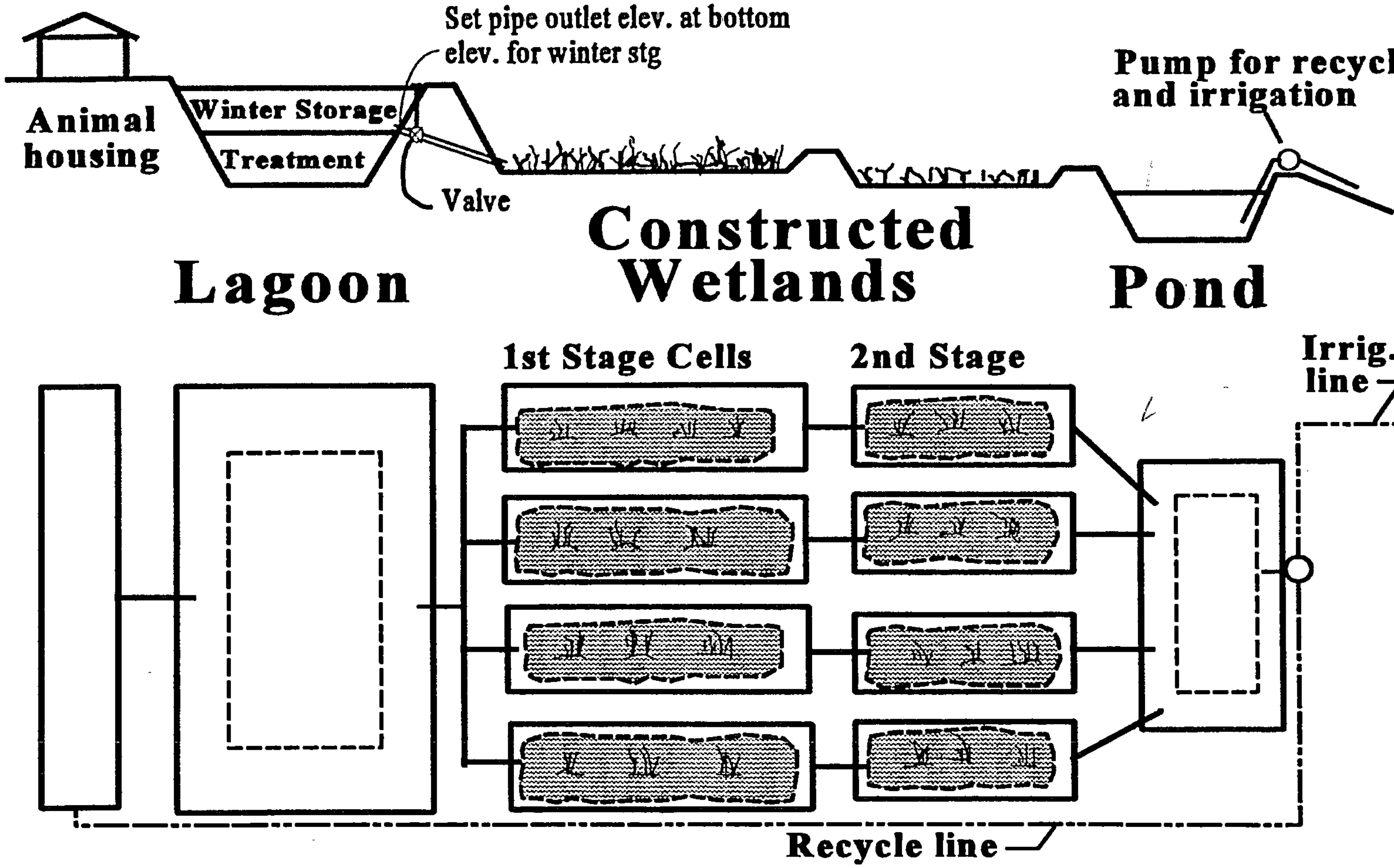


Figure 5: Typical layout of a lagoon / wetland / storage pond system for waste treatment

embankments must be high enough to protect the system from overtopping during a specific design storm (i.e., 25-yr, 24-hr). These embankments must have an emergency bypass set at such an elevation that discharge will only occur when the design storm has been exceeded.

Design height for the outer embankments should be based on the following increments of depth:

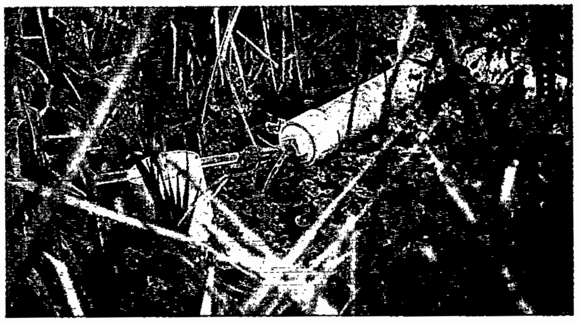
a. Normal design flow: Based on type of vegetation; typically 8 to 12 inches (20 - 30 cm).
b. Accretion: Based on the design life of the system; allow 1.0 in (2.5 cm) per year.
c. Design storm: Includes direct precipitation on the wetland plus runoff from embankments and, if inflow is unrestricted, precipitation on the pretreatment surface.
d. Ice cover: If the system will operate in winter, allow depth equal to the ice thickness expected during some design period (i.e., once in 25 years).
e. Freeboard: A safety factor of at least 12 inches (30 cm) is recommended.
f. Emergency bypass: As required by the type of bypass.

Design height for the divider embankments must include at least items a, b, and e, above.

2. *Width of embankments*: Outer embankments should be at least 15 ft (4.6 m) at the top to prevent burrowing animals from draining the system to the surrounding area. Inside slopes should be 2 horizontal to 1 vertical if this slope is part of an interior cell. Outside slopes should be no steeper than 2:1 but will usually be shaped to fit the site. Inside embankments should be wide enough at the top for easy maintenance. Top widths of 8 to 10 ft (2.4 - 3 m) are recommended so grass can be mowed with tractor-driven equipment and to reduce the potential for animals burrowing through dikes. Narrower dikes or embankments have been used, but these must be cut with hand mowers, and they are easily breached by muskrats.

□ **Liners**

The bottoms of all cells and insides of the outer embankments should be appropriately lined to prevent seepage. The discussion under *Site Evaluation, 1. Soils* should be reviewed to determine when compacted soil liners or manufactured liners should be used.



A properly sized orifice can control inflow rate, but an upstream filter is needed to prevent plugging.

□ **Inlet / Outlet Structures**

1. *Inlet structures*: A variety of inlet control structures have been used at livestock constructed wetland sites. These include simple overflow pipes with unregulated flow between the pretreatment unit and the upper wetland cells; pipes with orifice controls; and valves. Some of these discharge directly at the middle of the cell. Others have a gated or

slotted pipe which spans the width of the cell to ensure even distribution of flow upon entry. Other options for initial distribution include deep zones across the width of the inlet end and shallow dams with multiple slots or weirs across the top.

If wastewater will be stored in the pretreatment unit during winter, the invert elevation of the effluent pipe leading to the wetland should be in line with the bottom elevation for winter storage (see Figure 5).

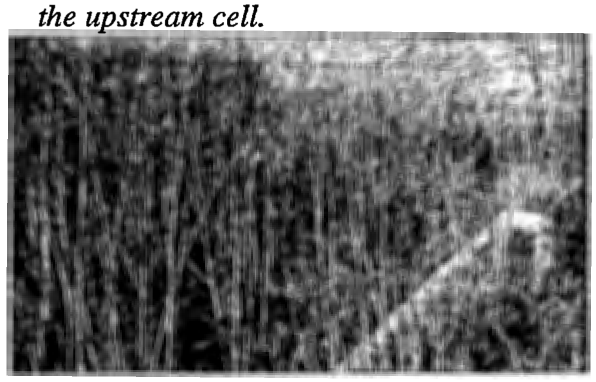
Some positive control is needed not only to prevent discharge to the wetland during the dormant season, but also to ensure a controlled release throughout the in-use period based on the water budget.

Plugging of control devices can be a problem. A buildup of a crystalline substance called struvite on the walls of piping systems for animal wastes has been a problem in some orifice control devices. Other devices have been plugged with debris from the pretreatment unit. Inlet screens or box screens should be used around the inlet pipes to prevent debris, including turtles, from entering the inlet line. Inlet structures should be observed daily for potential problems.

2. *Outlet structures*. The outlet structure is used to maintain the proper water level in the upstream cell and to control outlet flow rate. Several types of outlet control structures have been used. These include slotted pipes laid across the bottom of cells or slotted pipes buried in a shallow gravel trench at the downstream end of a cell. These are connected with a T section to a pipe that passes through the embankment to the downstream water-level control device. (See Figure 6.)

The water-level control section for this type outlet is typically an elbow attached with a swivel joint. The water level in the upstream cell is controlled by the invert elevation of the outlet pipe. The pipe can be tilted at the swivel/elbow connection, allowing the invert to be raised and lowered, which, in turn, sets the water elevation upstream. Water can be discharged directly at the invert (top photo below) or another section can be added to form a U, with another elbow and swivel opposite the first elbow and swivel (lower photo below). This section is then attached to a slotted pipe which can distribute the effluent across the head of the next cell.

This swivel pipe controls the water level in the upstream cell.



Two swivel elbows and a U are used here to redistribute flow through a header pipe.

Some of the slotted pipe headers have had a problem with plugging. For this reason other

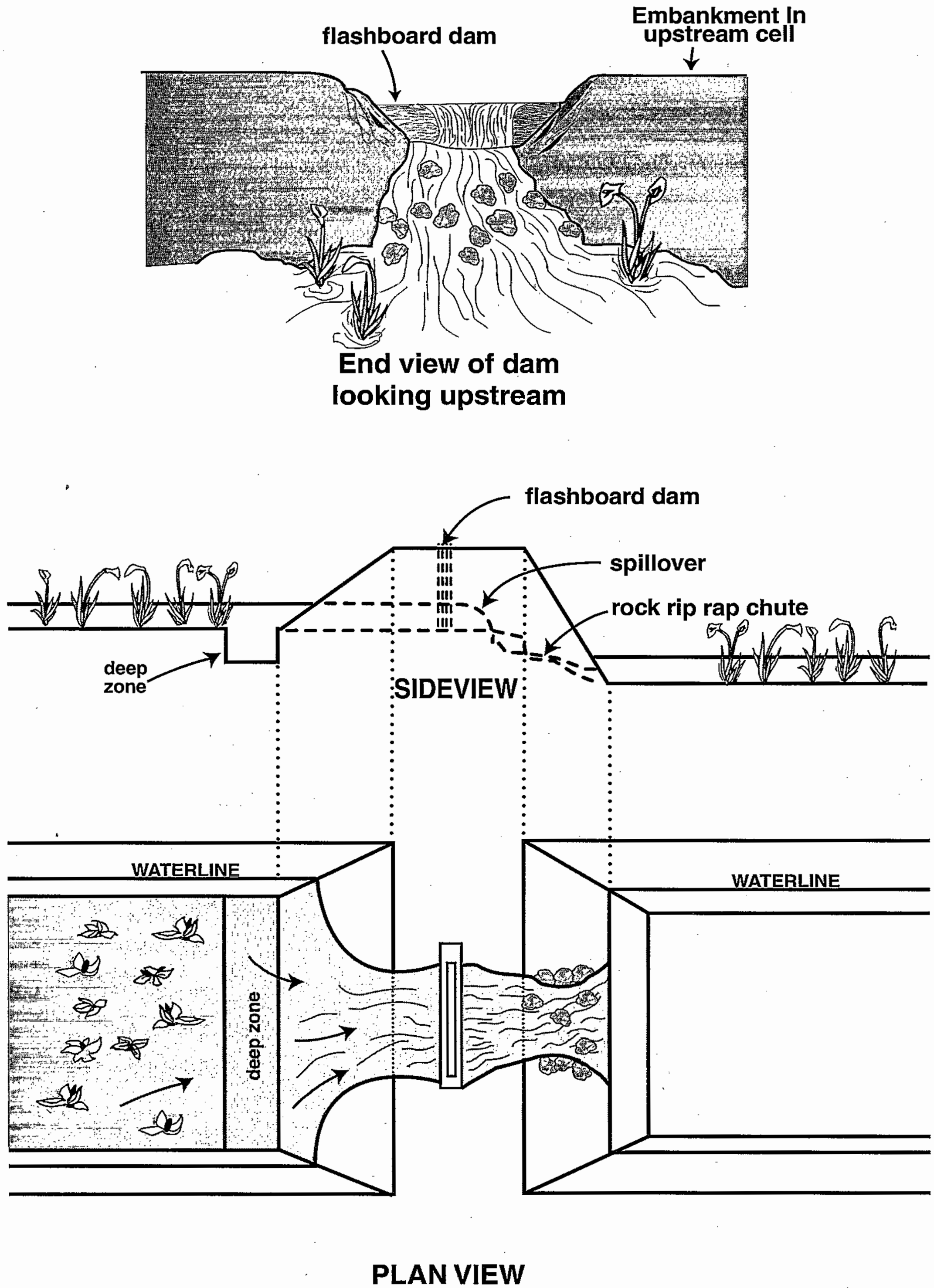


Figure 6: Flashboard Dam

types of outlet control structures are being explored. One approach is to install a deep zone across the outlet end of the cell with a flashboard dam set in the embankment to control upstream water level. Treated boards used for the dam can be removed or added as needed to control water level (Fig. 6). In addtion, various weir and drop box inlet controls might be considered.

☐ Water budget

A water budget is needed for design of the overall system and for management. Designers who plan many of these systems should consider developing a computer spreadsheet. A sample spreadsheet for a constructed wetland/land application treatment system is presented in Table 10. See also the following section on Operation and Maintenance.

Operation and Maintenance

1. *Operation*: Normal annual operation of the system will be dictated by the water budget, by visual inspection, by wastewater testing, and by common sense. Some of the key operational requirements include:

a. Maintaining water levels in the wetland cells as appropriate for the vegetation. In cold climates where continuous winter operation will be involved, increase water levels as needed prior to the first freeze.

b. Control flows into the wetland in accordance with requirements of the water budget. Adjust as needed for periods of drought, increasing inflow rates to ensure that vegetation at the extremities of the wetland are kept wet during dry times.

c. Ensure that water levels in the pre-treatment unit and downstream storage pond are lowered to appropriate levels in preparation for winter storage.

d. Collect samples and measure flow rates into and out of the wetland regularly. Determine treatment efficiencies and nutrient mass loadings.

e. Sample wastewater in the downstream storage pond prior to land application. Determine fill rates of the pond to determine total nutrient load available per year.

f. Revise water budget as needed.

2. Maintenance: Regular maintenance of the wetland system is essential and inevitable. If frequent inspections are ignored, rodents can destroy vegetation and embankments, pipes can become plugged, wastewater can short circuit through the cells, and the system can become inoperational in a short time.

A short list of important maintenance items is provided below. This is not intended to be an all-inclusive list:

a. Inspect inlet and outlet structures for plugging and damage on a daily basis.

b. Inspect embankments at least weekly for damage and make repairs as needed. Control rodent pests through removal or deterrents, such as electric fences.

c. Mow embankments regularly to allow for inspections and to enhance visual appeal.

d. Inspect and repair fences as needed.

e. Inspect vegetation throughout the growing

Table 10. Sample water balance spreadsheet for 2000 finisher swine with 400x400 ft lagoon and 26,400 ft^2 constructed wetland (CW).

Climat.	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	total
Precip.	5.6	5.4	6.0	5.9	4.9	5.0	4.5	4.0	3.8	4.2	5.0	5.2	59.5
Pan	3.2	3.8	4.0	4.0	4.3	5.1	5.6	6.2	4.9	4.3	4.0	3.8	53.2
Lake	2.2	2.7	2.8	2.8	3.0	3.8	3.9	4.3	3.4	3.0	2.8	2.7	37.4

Items Input	Volume (1,000 ft^3/mo)												
	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	total
Manure	11.2	10.1	11.2	10.8	11.2	10.8	11.2	11.2	10.8	11.2	10.8	11.2	131.70
Precip. lagoon	74.7	72	80	78.7	65.3	66.7	60	53.3	50.7	56	66.7	69.3	793.40
Precip. CW	12.30	11.90	13.20	13.00	10.80	11.00	9.90	8.80	8.40	9.20	11.00	11.40	130.90
flush*	0	0	0	120.3	124.3	120.3	124.3	124.3	120.3	0	0	0	733.80
runoff	4.7	4.5	5.0	4.9	4.08	4.17	3.75	3.33	3.16	3.50	4.16	4.33	49.58
Total	102.9	98.5	109.4	227.7	215.68	212.97	209.15	200.93	193.36	79.9	92.66	96.23	1839.38
Output	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	total
lagn evap	29.9	35.5	37.3	37.3	40.1	47.6	52.2	57.8	45.7	40.1	37.3	35.5	496.3
CW evap	4.93	5.85	6.16	6.16	6.62	7.85	8.62	9.55	7.55	6.62	6.16	5.85	81.92
							Net annual w.w. = total Input - total Output =						1261.16
Irrig ‡ (1000ft^3)	0	0	0	210.19	210.19	210.19	210.19	210.19	210.19	0	0	0	1261.16

*flush= fresh flush water; if recycled wastewater from the CW is used, flush = 0. Flush at 15 gal/hd/d.

season and replace plants that are not performing as expected.

f. Inspect and repair pumps and piping systems, if used.

Final Comments

The constructed wetland can be a very useful tool in managing animal wastes. It is not suitable for every operation, and, in fact, it may be undesirable in many locations.

Constructed wetlands must be properly planned, designed, constructed, and managed. Failure in any of these areas could result in failure of the system.

The constructed wetland is still a new method for treating animal wastes. Much has been learned, but much more remains to be learned. As more systems are installed and more information gathered, the design and management techniques will be refined further.

In the proper place and with proper management, the constructed wetland can be a valuable asset to the manager seeking an economical and environmentally sensitive way to treat animal wastes.

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Section II

Case Histories on Constructed Wetlands for Treating Animal Wastes

Swine:
Duplin County, NC
Sand Mountain, AL

Dairy:
Kosciusko County, IN
Desoto County, MS
Malden Valley, Ontario, Canada
Oregon State University, OR

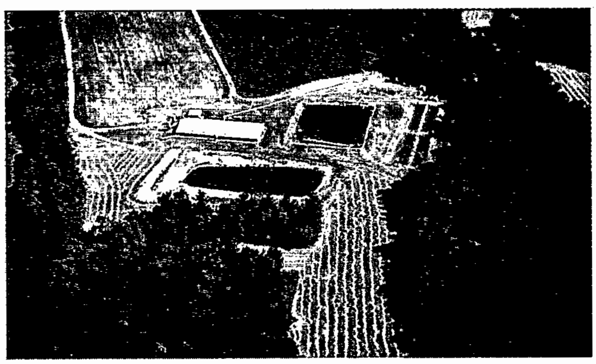
Poultry:
Auburn University, AL

Constructed Wetland to Treat Swine Wastewater
Duplin County, North Carolina

F. Humenik, PhD, M. Rice, M. Cook, PhD, and S. Broome, PhD*
P. Hunt, PhD, and A. Szogi, PhD,** G. Stem and M. Sugg,✣ and G. Scalf✣✣

Introduction

This project was located at a swine facility housing 2600 nursery pigs having an average weight of 11.8 kg. The swine are housed in a single building which is flushed six times per day into a 0.24 ha anaerobic lagoon. Wastewater from the lagoon is irrigated directly onto nearby pasture and crop land. The constructed wetland is operated as an independent, no-discharge system with all effluent being returned to the lagoon for land application.



Aerial view of lagoons and wetland

The project was undertaken to address concerns and to answer questions about the ability of wetland systems to (1) produce an effluent that met discharge limits for nitrogen and phosphorus and (2) remove high percentages of nitrogen from wastewater. As this description shows, these goals were sometimes met individually but could not be met at the same time. The performance of the system depended on the loading rate at which the effluent was discharged to the wetland.

Regulatory Context

To discharge the treated effluent to a local stream, the wetland system had to produce effluent concentrations with nomore than 4 mg/L total nitrogen in the summer and 8 mg/L in the winter, as well as 2 mg/L total phosphorus year-round.

Wetland Design

The wetland was designed according to guidance on nitrogen loading rates. For municipal wastewater wetlands, the recommended loading rate was total Kjeldahl nitrogen (TKN) or ammonia nitrogen (NH_3-N) at 18 kilograms per hectare per day (kg/ha/day). For livestock wastewater wetlands, recent guidelines varied from 10 to 15 kg/ha/day. While this system was being designed, the Tennessee Valley Authority (TVA) issued new criteria of less than 3 kg/ha/day for wetlands designed to meet advanced discharge standards. As a result the system was designed for a low TKN loading rate of 3 kg/ha/day.

Six 3.6 x 33.5-meter wetland cells were constructed in 1992 (Figure 1). They were

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divided into three parallel systems of two cells in series. Wetland system 1 contained rushes and bulrushes; wetland system 2 contained bur-reed and cattails; and wetland system 3 contained soybeans in saturated soil culture and rice. Due to different operational parameters for wetland system 3, a summary of results was not available.

The cell bottoms and sidewalls were lined with clay and then covered with 20 to 30 cm of loamy sand soil. Lengthwise slopes were 0.2 percent or less. Water depth at the end of the slope was maintained below 15 cm.

Monitoring

V-notch weirs and PDS-350 ultrasonic open-channel flow meters were installed at the inlet and outlet of each of the three wetland systems. Five ISCO 3700 samplers were installed; one sampler collected samples of the wastewater influent and the other four sampled the water at the end of each single cell. The water sampler combined hourly samples into composites. A CR7X data logger with two multiplexers were installed for hourly acquisition of flow, weather, and soil redox potential data.

Operation and Performance

From May 1993 to June 1994, wastewater was applied to the constructed wetland at a rate of 3 kg/ha/day of TKN. Lagoon wastewater was diluted about tenfold with fresh water to meet the low TKN application rate and to make up for evapotranspiration during summer. As a result of the increased dilution, TKN concentrations in the influent wastewater were lower in the summer. Wastewater input to the wetland was continuous, and flow control valves in a mixing tank were set to provide the desired proportion of lagoon liquid and diluted water. Effluent TKN ranged from about 30 to 50 mg/L total nitrogen for winter.

At the 30 mg/L loading rate, effluent TKN was generally less than 8 mg/L. At the 50 mg/L loading rate, effluent TKN was generally more than 10 mg/L. TKN removals on a mass basis for the 3 kg/ha/day loading rate were 96 and 91 percent for wetland systems 1 and 2, respectively (see Table 1). The effluent sometimes met local stream discharge requirements of 4 mg/L total nitrogen for summer and 8 mg/L total nitrogen for winter.

Table 1. Effluent TKN and TP Concentrations in Response to Different Mass Loading Rates.

TKN Loading (kg/ha/d)	Effluent TKN		Effluent TP	
	mg/L	% Removal	mg/L	% Removal
3	<8	91-96	7	73
10	10-20	73	10-20	10-17

Effluent total phosphorus averaged about 7 mg/L for the TKN loading rate of 3 kg/ha/day. In general, effluent total phosphorus concentrations exceeded the discharge allowance of 2 mg/L year-round. Total phosphorus removal on a mass basis was about 73 percent.

From June 1994 to January 1996, the TKN loading rate was increased to 10 kg/ha/day with the new goal being maximum nitrogen removal rather than meeting stream discharge requirements. After increasing the TKN loading rate, effluent TKN concentrations generally exceeded local stream discharge requirements. However, at the higher loading rate, both wetland systems still removed more than 73 percent of TKN on a mass basis.

At the higher TKN loading rate, effluent total phosphorus ranged from 10 to 20 mg/L Only 10 percent and 17 percent of the total phosphorus was removed by wetland systems 1 and 2, respectively. Total phosphorus removals on a mass basis decreased significantly with time and higher TKN loading rates.

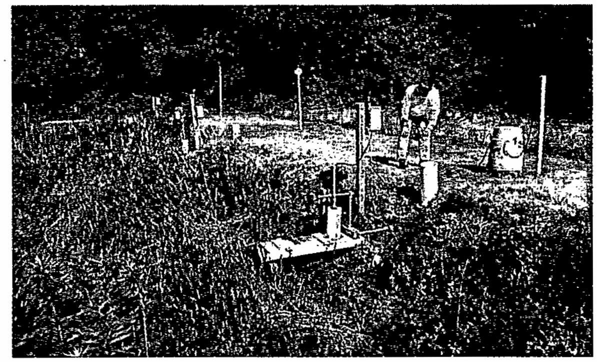
Effluent total organic carbon concentrations varied widely for both TKN loading rates. The wetland systems did not appear to affect total organic carbon concentrations (TOC) and, in some cases, TOC increased.

Conclusions

At the loading rate of 3 kg/ha/day of TKN, the wetland discharge met nitrogen criteria during some time periods. The discharge did not meet phosphorus criteria, except temporarily in wetland system 2 before TKN loading was increased.

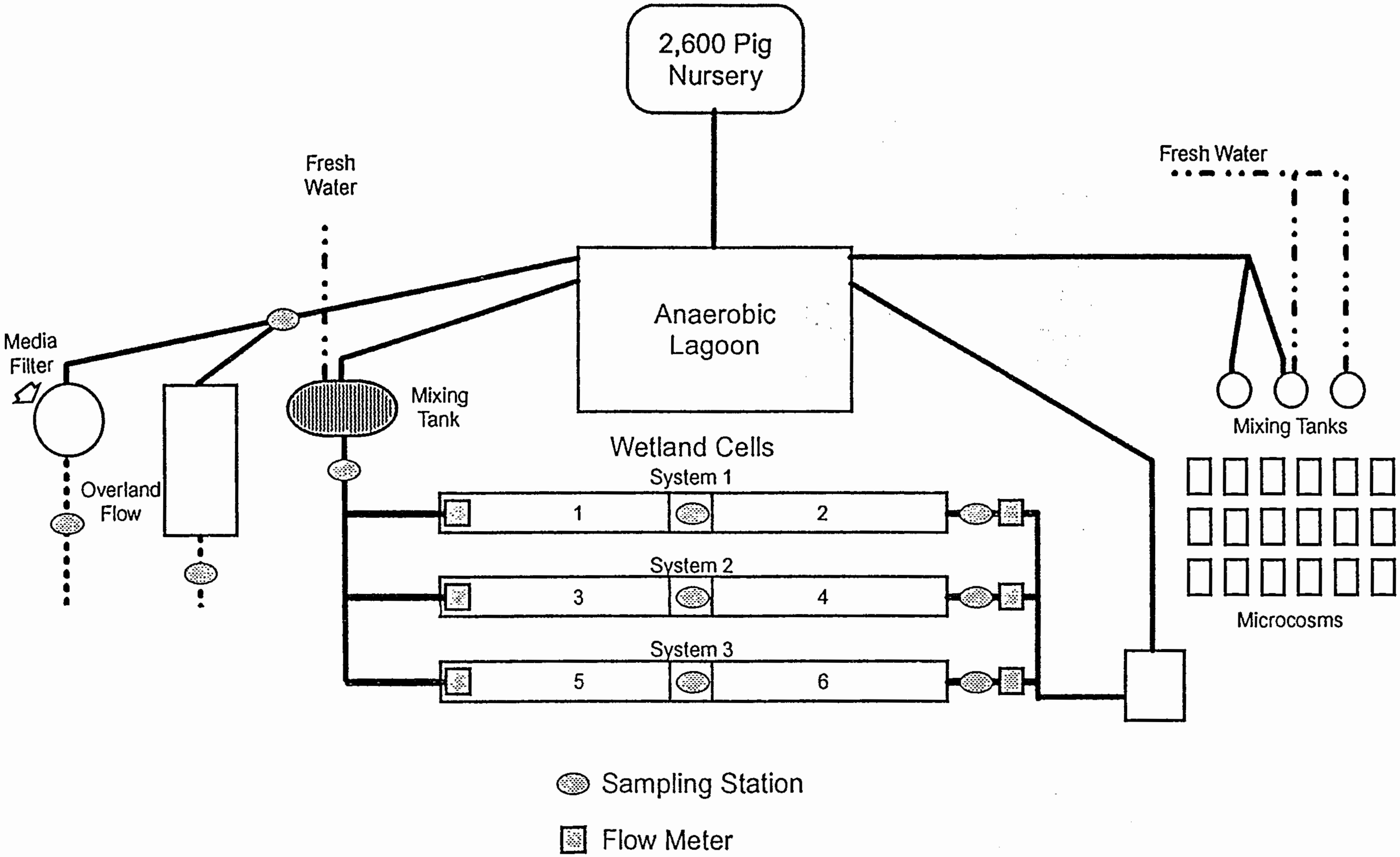
At the loading rate of 10 kg/ha/day of TKN, the wetland discharge often exceeded the nitrogen criteria and consistently exceeded the phosphorus criteria. However, the wetland did meet the secondary goal of high nitrogen removal with removal efficiencies of about 73 percent.

While wetlands can significantly reduce nitrogen mass loading, they do not appear to be a viable treatment method to achieve stream discharge since the procedure of diluting livestock wastewater to obtain constructed wetland loading rates for advanced discharge standards is not consistent with basic principles of wastewater volume reduction and pollution prevention.



The wetland system is very well monitored.

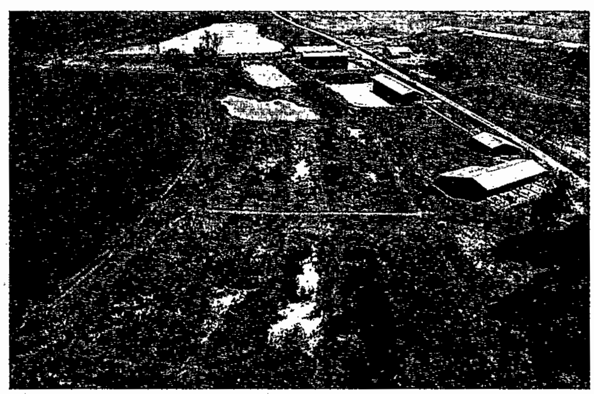
To further evaluate the potential for nitrogen removal at higher loading rates, the TKN loading rate has been increased to 15 kg/ha/day. In addition, researchers are evaluating model unit processes that could improve treatment, such as overland flow, media filter, aerated lagoon, and unaerated lagoon. The goal of the current evaluation is to identify a treatment train of aerobic and anaerobic unit processes that provide maximum removal of phosphorus and nitrogen. The ultimate objective is to incorporate wetland systems into livestock wastewater management programs that reduce costs and land requirements to swine producers.


2,600 Pig Nursery
Fresh Water
Fresh Water
Anaerobic Lagoon
Media Filter
Overland Flow
Mixing Tank
Mixing Tanks
Wetland Cells
System 1
1
2
System 2
3
4
System 3
5
6
Microcosms
Sampling Station
Flow Meter

Performance of a Full Scale Constructed Wetland Treating Swine Lagoon Effluent in Northern Alabama

T. A. McCaskey, PhD., and T. C. Hannah*

A full scale constructed wetland was built in the fall of 1988 at the Sand Mountain Agricultural Substation in Crossville, Alabama. The wetland size was based on BOD_5 design criteria(1 kg BOD_5/150 m^2/day) for a 500 pig-per-year farrow-to-finish production facility (Hammer et al., 1993). The waste treatment system consists of three anaerobic lagoons (two primary and one secondary), a 0.1 hectare shallow mixing pond, and five series of dual cell wetlands (Figure 1). Each wetland cell was excavated 1.5 meters deep, 52 meters long, and 7.8 meters wide with an earthen bottom sloped lengthwise less than one percent. The five cells in the upper tier and five cells in the lower tier have a total surface area of 0.405 hectares. No plastic liner or clay backfill was used to seal the bottom of the cells.



Aerial view of the wetland system at the Sand Mountain Experiment Station

In the spring of 1989, emergent aquatic plants were planted in the wetland cells. Species included broadleaf cattail (*Typha latifolia*), soft stem bulrush (*Scripus validus*), and rush (*Juncus effusus*). Common reed (*Phragmites australis*), giant cutgrass (*Zizaniopsis milliacea*), and narrowleaf cattail (*Typha angustifolia*) were planted in 1990. The wetland cells were kept moist with pond water for two growing seasons to allow the plants to become established before wastewater was introduced into the wetland cells.

Table 1. Treatment efficiency of a two-stage constructed wetland treating swine lagoon effluent over a 55-month period.[a]

Pollutant	Lagoon Effluent	Wetland		% Change
		Inflow (mg/L)	Outflow (mg/L)	
TKN	155.3	73.7	12.2	83.4
NO_3-N	<1	<1	<1	<1
NH_4-N	126.0	55.6	8.6	84.5
TP	51.1	28.4	6.8	76.1
BOD_5	146.3	76.6	7.9	89.7
COD	554.6	319.9	64.2	79.6
TSS	241.5	135.7	15.5	88.6

a. Lagoon effluent plus dilution water from a farm pond

Manure from a swine farrowing house, nursery, and finishing house were flushed into two primary lagoons, which overflowed into a secondary lagoon. Effluent from the secondary lagoon was combined with pond water (2.7 parts to 1 part) in a 0.1 hectare mixing pond to reduce the ammonia content of the lagoon effluent below 60 mg/L.

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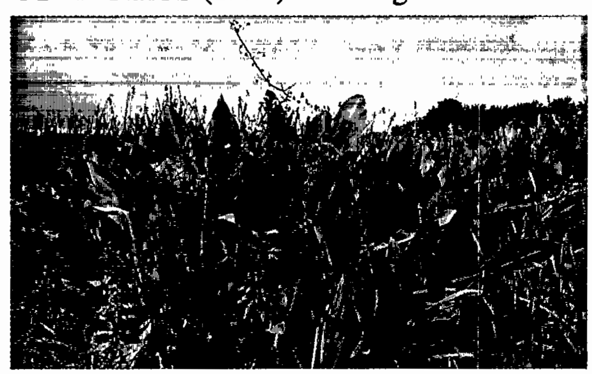
Effluent from the mixing pond was distributed equally into each of the five cells in the upper tier of wetland cells (each 0.4 hectares). Effluent from each upper cell flowed into a corresponding lower cell.

Based on the mean hydraulic flow rates over a 55-month period, the theoretical hydraulic retention time for both tiers of cells was 18 days, and the mean BOD_5 loading rate was 5.9 kg BOD_5/ha/day. Flow rates were monitored daily excluding weekends and holidays, and wastewater samples were collected and analyzed biweekly. Data collected over a 55-month period (Table 1) indicate that the constructed wetlands were highly efficient at treating swine lagoon effluent. Total Kjeldahl nitrogen (TKN) content of the wetland inflow was reduced from 73.7 mg/L to 12.2 mg/L after treatment, an 83.4% reduction. Ammonia nitrogen represented 75.4% of the TKN in the wetland inflow, and the NH_4-N was reduced through wetland treatment from 55.6 to 8.6 mg/L, a reduction of 84.5%.

The influent to the wetland, a combination of lagoon effluent and pond water, was essentially anaerobic. Since no dissolved oxygen was present in the influent wastewater, ammonia was not readily converted to nitrate; thus, NO_3-N concentrations in the wetland effluent were always less than 1 mg/L. Total phosphorus (TP), BOD_5, COD, and total suspended solids (TSS) were reduced 76.1%, 89.7%, 79.1%, and 88.6%, respectively.

Most of the treatment occurred in the upper tier of wetland cells (1A through 5A in figure 1), with treatment results shown in Table 2. The USDA-NRCS (1991) guidelines recommended that effluent concentrations from animal waste constructed wetlands be <30 mg BOD_5/L , <30 mg TSS/L, and <10 mg NH_4-N/L. Treatment by the upper tier of cells was sufficient to meet the effluent criteria for BOD_5 and TSS, but both the upper tier and lower tier of cells were required to reduce NH_4-N to the acceptable levels.

The BOD_5 loading rate for the entire wetland, including the upper and lower tiers of cells, was 5.9 kg BOD_5/ha/day. This loading rate is approximately 61 kg BOD_5/ha/day less than the rate suggested by Hammer et al. (1993) and USDA-NRCS (1991). Based on average concentrations of analytes in the wetland effluent during the 55-month study, the 5.9 kg BOD_5/ha/day loading rate met the effluent criteria suggested by USDA-NRCS (1991). However, during the winter and early spring months, when heavy rainfalls occur in Alabama, even this BOD_5 loading rate was too high, and on several occasions NH_4-N concentrations in the wetland effluent were in excess of the 10 mg/L limit suggested by USDA-NRCS (1991). Although the wetland


Sagittaria thrives in treated swine effluent.

effluent cannot be legally discharged and must be recycled, minimum treatment efficiencies for wetlands treating animal manure lagoon effluents should be

Table 2. Wastewater treatment efficiency occurring in upper and lower tiers of wetland cells.

Pollutant	**Upper Tier**			**Lower Tier**		
	Inflow	Outflow	Decrease	Inflow	Outflow	Decrease
	mg/L	mg/L	%	mg/L	mg/L	%
TKN	73.7	27.1	63.2	27.1	12.2	55.0
NO_3-N	<1	<1	--	<1	<1	--
NH_4-N	55.6	20.7	62.8	20.7	8.6	58.5
TP	28.4	12.7	55.3	12.7	6.8	46.5
BOD_5	76.6	16.8	78.1	16.8	7.9	53.0
COD	319.9	107.7	66.3	107.7	64.2	40.4
TSS	135.7	19.1	85.9	19.1	15.5	18.8

mandatory because there can be no guarantee that wetland effluents will be totally contained during high rainfall events that occur during the winter months.

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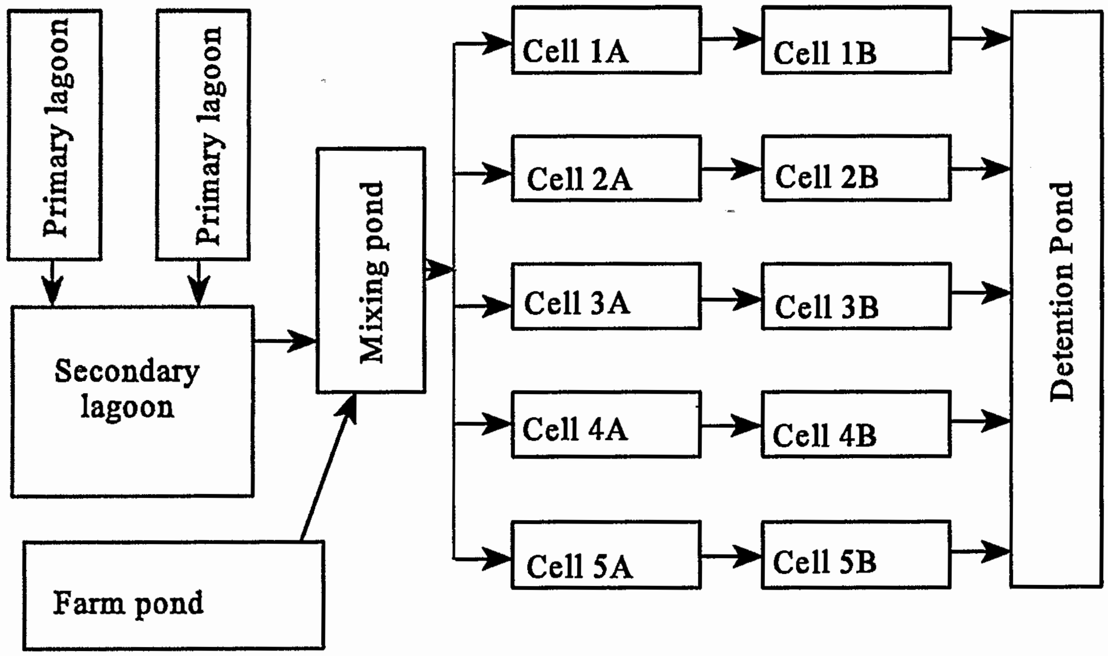


Figure 1. Diagram of the Sand Mountain Constructed Wetland System at the Agricultural Experiment Station, Crossville, AL

Tom Brothers' Dairy Constructed Wetland

Richard P. Reaves, PhD., and Paul J. DuBowy, PhD.*

Introduction

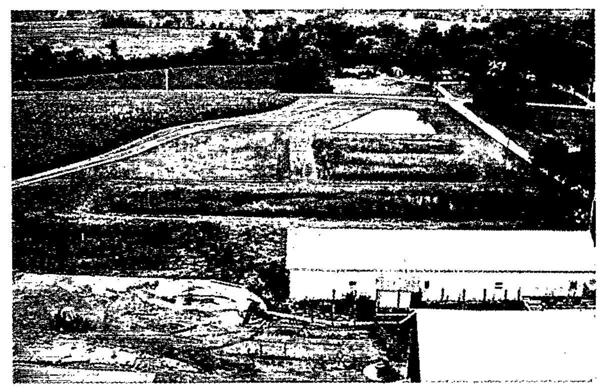
The Tom Brothers' dairy, located in Kosciusko County, Indiana, is a family operation owned by Garry and Max Tom. The dairy milks about 70 cows and is therefore classified as a nonpoint source facility rather than a point source subject to the more stringent regulations of the Indiana Confined Feeding Law.

Like many small dairies in northern Indiana the Tom Brothers' dairy is located upslope of a lake formed by glacial recession. The lake in this case is Tippecanoe, which has been developed for residential and recreational use. In the early 1990's there was concern that the Tom Brothers' dairy was adversely impacting water quality in the lake In summer, the lake would be closed to swimming because of elevated fecal coliform levels in a portion of the lake near the dairy.

Although Garry and Max Tom believed their operation was not the cause of the high bacterial levels in the lake, they chose to participate in a constructed wetland demonstration project with the USDA Soil Conservation Service (now the Natural Resources Conservation Service), the Indiana Department of Environmental Management, and Purdue University. The project would augment Tom Brothers' existing waste management system; demonstrate a relatively new waste management option; and determine the degree to which the dairy might be contributing to water quality problems in Tippecanoe Lake.

The waste management system

Waste at the dairy is scraped daily from the barns to a stack pad. The stacked manure is removed regularly and land applied to notill crops on the farm. Barn wastewater (750 L d^{-1}) is delivered to a septic manure pit located beneath the stack pad where solids are settled and separated from the wastewater. Liquid from the stack pad drains into the pit through slots beneath the pad.



Wetland as viewed from adjacent silo (Courtesty Brian Miller)

The constructed wetland consists of two cells in series (see Figure 1). The first cell is a rectangle (64.6 x 14 m). The second cell is horseshoe-shaped, with the two arms each being 32.3 x 14 m and the upper end or crossover being 9 x 6.1 m. The bottom slope in both cells is 0.25%, resulting in a depth differential of 16 cm from inlet to outlet.

Cell 1 and the first half of Cell 2 are lined with plastic to prevent groundwater

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contamination. Soils beneath the last half of Cell 2 have sufficiently low conductivity to preclude the need for a liner.

Both cells were hand planted with broadleaf cattail (*Typha latifolia*) obtained from roadside ditches within the county. Smartweed (*Polygonum* spp.) and water grass (*Echinochloa walteri*) volunteered in the system. The first cell was a near monoculture of cattails, and the second cell became a mix of cattails and water grass as predominant plants. Smartweed was a marginal plant in each cell, growing around the edges and in shallow areas. Overflow from the manure settling pit discharges by gravity to the upstream end of the first wetland cell The effluent is distributed across the width of the cell through a slotted horizontal pipe. In addition to the pit discharge, yard runoff is diverted around the stack pad and delivered to Cell 1 at a point approximately 60% of the distance from the upper end; this discharge enters the side of the cell and is not distributed across the cell.

Effluent from Cell 1 flows into the upstream arm of Cell 2 and is redistributed across the width of the cell through a slotted pipe, in the same manner as delivery of the pit effluent to Cell 1. Effluent from Cell 2 enters a holding pond (35 x 35 m surface water dimensions and depth of 1.8 m when full). During periods of overflow, the holding pond discharges into an infiltration strip for final disposal.

Results and Discussion

The wetland became operational in the spring of 1994 and was monitored through 1995. Water samples were collected from the inlet to Cell 1, from the point where the yard runoff entered Cell 1, from the inlet and outlet of Cell 2, and from the holding pond, the infiltration area, and a roadside ditch downhill of the infiltration area. The ditch received seepage water from the a subsurface tile beneath the infiltration area as well as road runoff. Samples were collected at least twice monthly during the growing season. On some of the sample collection dates, the wetland cells had no standing water. On those dates a "no flow" reading was noted. Samples were collected from the holding pond only on those sampling dates when flow was occurring in any part of the wetland system.

Samples were evaluated for five-day carbonaceous oxygen demand ($CBOD_5$), total suspended solids (TSS), total Kjeldahl nitrogen (TKN), total phosphorus (TP), reactive phosphorus (PO_4-P), ammonia nitrogen (NH_4-N), nitrite nitrogen (NO_2-N), and nitrate (NO_3-N). Fecal coliform bacteria were evaluated at the outflow of each wetland cell and in the holding pond. They were not evaluated at the initial inlet points to Cell 1 because high suspended solids concentrations created problems in conducting the tests. Beginning in July 1994, pH, conductivity, temperature, and dissolved oxygen were added to the analyses.

No data are presented for 1994 because the pit had been pumped out the previous fall and very little waste discharged to the wetland. The wastewater entering Cell 1 was not typical of liquid dairy waste. During late summer Cell 1 went dry for lack of both rainwater and wastewater, so there was no flow into either wetland cell.

In 1995, wastewater from the pit and runoff from the lot entered the wetland, and the inflow concentrations were like those of a typical dairy. In early spring, wetland performance was not as effective as later in the season. This was, in part, due to the heavy flush of waste into the system from spring rains, the cool temperatures which slowed microbial growth, and the immaturity of wetland plants early in the season. After the spring rains, the weather turned dry, and flow through the system was greatly reduced. The cells were virtually dry by September, and inflow rates did not return to normal until late October. The low rainfall levels from late spring through summer resulted in increased detention times and improved performance.

Table 1 shows the average annual concentrations of various constituents and the percent difference between the inflow and outflow of Cell 1 and between the inflow to Cell 1 and the outflow of Cell 2. It should be noted that the term "percent difference" is used rather than "percent removal efficiency" because the change in concentrations is affected by dilution by direct precipitation on the wetland cells and also by the fact that runoff water entered Cell 1 at a point along its width, as noted above. Thus, there was, indeed, an overall reduction in concentrations but the differences do not necessarily reflect only the percent reductions due to treatment. A mass balance was not conducted because a rain gage was not installed and information on seasonal evapotranspiration rates were not available for the various plants for this region.

Table 1. Treatment efficiency for a two-cell wetland treating runoff from the Tom Brother's Dairy in Indiana.

Constituent	**Cell 1 Inlet Concentration**	**Cell 1 Outlet Conc. (% diff.)**		**Cell 2 Outlet Conc. (% diff.)**	
TKN (mg/L)	215.3	113.1	(47)	30.4	(86)
NH_4-N (mg/L)	199.4	99.8	(50)	21.6	(89)
PO_4 (mg/L)	47.3	28.9	(39)	10.0	(79)
TP (mg/L)	25.3	10.8	(57)	4.2	(83)
$CBOD_5$ (mg/L)	910.3	155.6	(83)	67.6	(93)
TSS (mg/L)	483.4	113.2	(77)	30.7	(94)

Table 2 presents data on samples from the holding pond, the infiltration area, and the ditch. Some increases in concentrations occurred for nearly all constituents. This is probably the result of algal growth in the pond. It should also noted that, although only two samples were collected from the ditch, the concentrations of all potential pollutants were low.

Table 2. Average concentrations of wastewater constituents in the holding pond, infiltration area, and ditch (1995).

Constituent	Holding Pond	Infiltration Area	Ditch
TKN (mg/L)	22.8	20.2	1.4
NH_4-N (mg/L)	10.0	<0.02	<0.02
PO_4 (mg/L)	3.1	1.4	<0.02
TP (mg/L)	4.3	5.0	<0.02
$CBOD_5$ (mg/L)	29.0	71.6	9.3
TSS (mg/L)	61.0	30.0	16.5

Summary

It became evident through this study that some storage capacity is needed upstream of the wetland to allow wastewater to be held during the dormant season and to allow proper timing of the effluent to the wetland in conjunction with wet and dry periods. Excess water can be used to dilute the waste and to maintain flows during dry seasons.

The study at the Tom Brothers' Dairy indicates that high levels of pollutant removal can be achieved. It should also be noted that a large measure of the success of this project is due to the good management of the Tom brothers. A constructed wetland was installed on a similar sized dairy in northern Indiana, and it failed for lack of good management. Fences must be maintained and water levels managed, among other things. In other words, some work and commitment are required on the part of the farmer if the wetland is to be successful.

As result of this study, it was determined that the pollution in the downstream lake was not attributable to the Tom Brothers' Dairy.

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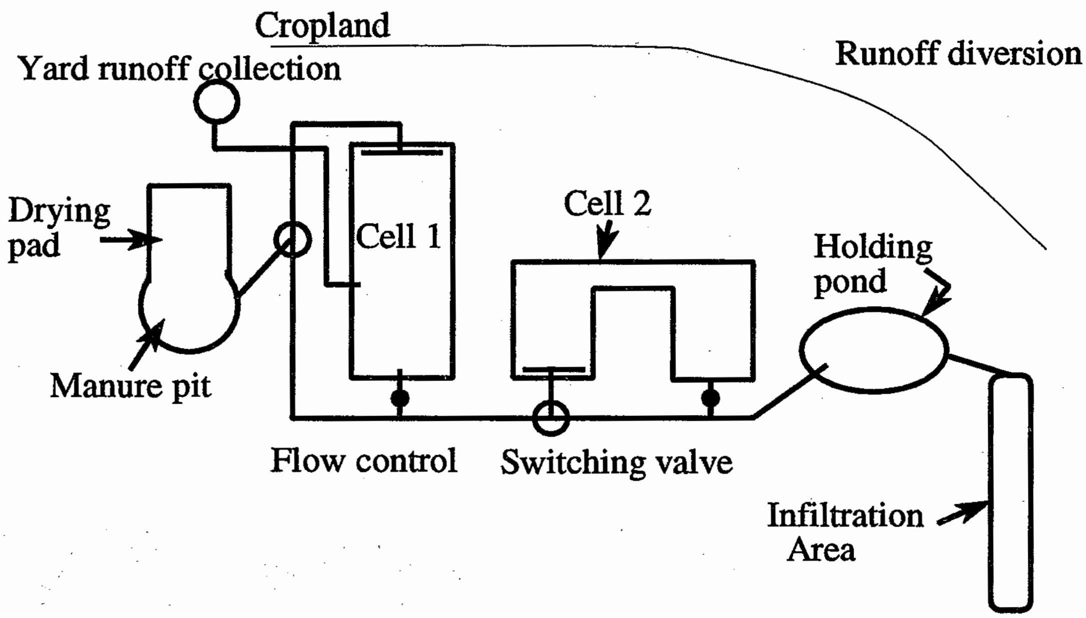

Figure 1. Generalized layout of waste treatment system at Tom Brothers' Dairy

A Constructed Bulrush Wetland for Treatment of Cattle Waste

Charles M. Cooper, PhD.* and Sam Testa III**

Introduction

Processing and disposing of concentrated on-farm animal waste, a major source of water quality deterioration, is a concern of the Natural Resources Conservation Service (NRCS) and regulatory agencies. Several projects for evaluating the ability of constructed wetlands to process animal waste have been initiated across the United States. As a result, optimal design criteria for such future animal waste management systems may be forthcoming. The Mississippi NRCS and the Agricultural Research Service (ARS) National Sedimentation Laboratory in Oxford, Mississippi, cooperated on an on-farm dairy waste treatment project which used a constructed bulrush wetland for processing. Herein we present findings from three years of operation and make suggestions for future design criteria for such systems.

Development of the Study Site

The Alan Scott dairy farm is located in DeSoto County, in extreme northern Mississippi, approximately 5 mi ESE of Hernando. During the study period an average of 80 (60 to 100) Holstein cattle (approximate weights of 1000 to 1200 pounds each) were milked twice daily in a concentrated animal feeding operation where they were held for approximately 6 hours per day. Total runoff area for the milking parlor and concrete loafing area where animals were confined during milking was 351.5 m^2. Total waste production in this area was estimated at 10,336 liters per day. Wastes drained through 15.24 cm (6 in) diameter PVC pipe to a 42 m x 52 m settling lagoon. The lagoon received input from milking equipment and tank cleanings, milking barn washing, loading area runoff, and rainfall. Export from the lagoon, drawn

Cell 2 with walkways (Summer 1991)

from approximately 0.3 m below the water surface, traveled through 7.62 cm (3 in) diameter PVC pipe to three parallel constructed wetland cells, each 6 m wide and 24 m long (Figure 1). Wastewater entered the cells through a horizontal, perforated section of pipe which spanned the width of the cell to prevent short-circuiting or channel flow. The pipe was elevated 20 cm above the water surface to prevent settling of solids and to allow for easier periodic cleaning.

Land slope was such that only part of the bottom of the cells was excavated; the remainder of the bottom and levees was built from soil excavated from the lagoon to create an approximate 0% slope system. Construction occurred in April, 1990, and

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constructed wetland cells were planted immediately in bulrush (*Scirpus validus*) at 0.3 m intervals with rhizome cuttings purchased from a wildlife supply company. Subsequent rains, supplemented with water pumped from the lagoon and well water, maintained standing water in the cells for the remainder of the year. Water level in the lagoon increased slowly because of high evaporation rates and lateral seepage through levees until the basin sealed. An insufficient amount of water accumulated in the lagoon to allow a gravity fed water supply to the cells during 1990. Bulrush growth in the cells was rapid. By September, 1990, the cells were covered by a uniformly dense monoculture with the majority of culms supporting flowering/seeding heads. Natural senescence occurred in November and December. Re-emergence of bulrushes from rhizomes occurred in February, 1991, through the litter created by the previous year's growth. Duckweed (*Spirodela polyrhiza*) spread to cover nearly all available water surface by May, 1991. In April, gravity flow from the lagoon to the wetland cells began functioning. Discharges to cells were calibrated to yield 3.0 L/min using in-line valves. Water depth in the cells was a maximum of 0.3 m.

Rapid water level decline in the anaerobic lagoon during summer, 1991, prompted a reduction of cell inflow rates to 0.5 L/min, but settling of solids in pipes and valves generally resulted in lower rates. Standpipes were fitted with threaded end caps containing orifices sized to achieve desired flow rates. Original valves were opened fully to prevent occlusion. Because of variations in flow a 4,000 L constant head tank was placed on the lagoon levee and connected to the supply pipe that led to the cells. A timer-controlled electric pump maintained water in the tank, creating constant hydraulic head and, thus, producing constant inflow. Using this method, a cell inflow rate of 1.0 L/min. was implemented, and the frequency of remedial action was greatly decreased. Also during the summer, 1991, another cell, Cell 4, was constructed in series with Cell 1 to allow greater loading capacity and assessment of further treatment (Fig. 1).

Mats of decaying vegetation from previous years growth increased during 1992-1994, and caused sparser and clumpy emergence of the bulrush within the treatment cells. Growth of volunteer vegetation such as Smartweed (*Polygonum* sp.) and cutgrass (*Leersia* sp.) increased also. Removal of the decaying vegetative mat from affected areas with hand tools restored bulrush growth.

Methods

Eighteen parameters were monitored at biweekly intervals from May, 1991, through April, 1994. Total rainfall for the two week period prior to sampling and lagoon water column depth were recorded. Lagoon samples were taken from the outflow control platform at a depth of 0.3 m below water surface. Flow rate, temperature, conductivity, dissolved oxygen, pH,, total solids, dissolved solids, suspended solids, filterable ortho- phosphorus, total phosphorus, ammonia nitrogen, nitrate nitrogen, total chlorophyll, sediment redox potential 5-day carbonaceous biochemical oxygen demand, and total coliforms were measured at cell inflow and outflow. Chemical oxygen demand was determined at all sampling sites quarterly.

Early in the project 3 walkways were con-

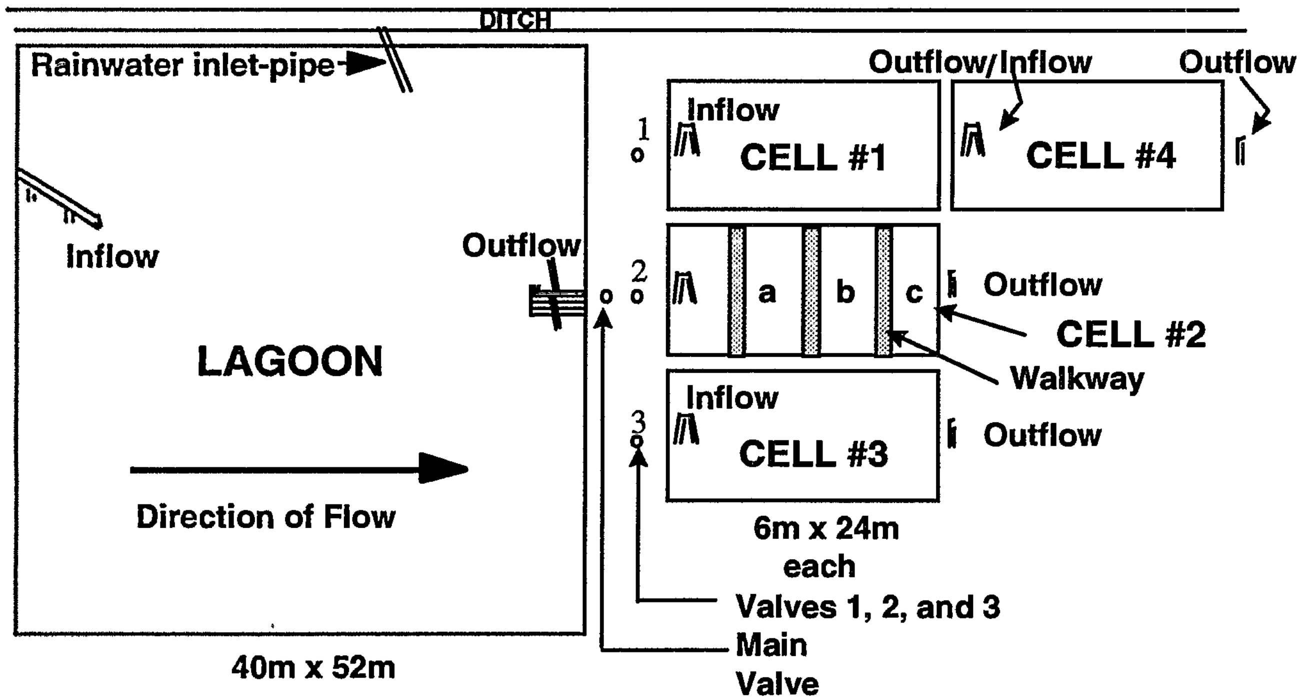

Figure 1. Layout of lagoon\wetland cell system at Hernando Wetland on Alan Scott Farm, DeSoto County, Mississippi, USA.

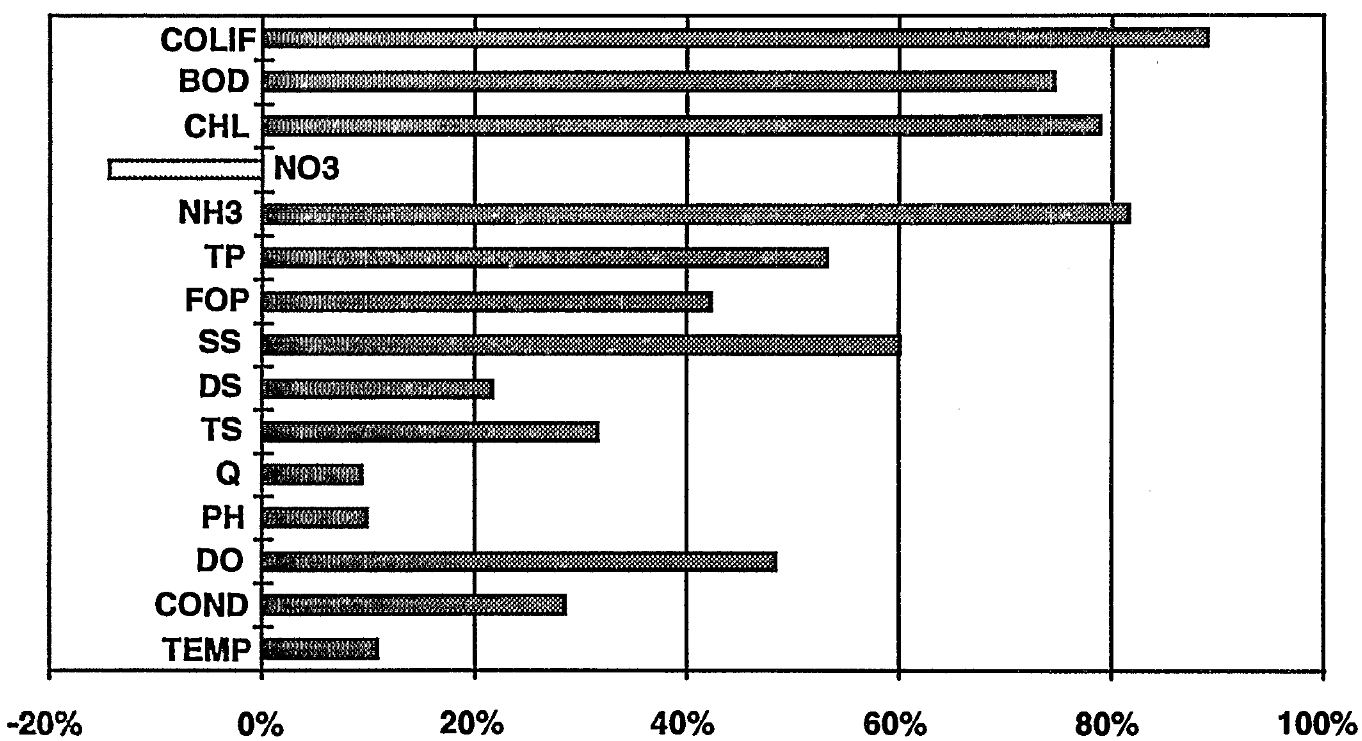

Figure 2. Mean percent reduction for each parameter.

structed equal distances apart in Cell 2 (Fig.1) so that in-cell measurements could be taken at intervals without disturbing the cell. Results from in-cell processing and a more detailed discussion of the project were given earlier by Cooper et al. (1995).

Water quality parameters were measured according to APHA (1989) guidelines. Cells did not continually discharge due to evapotranspiration, ground infiltration and seepage. When such times coincided with sampling visits, water quality samples and measurements from non-discharging outflow stations were taken by tilting the standpipe until flow occurred. For computing loading rates of pollutants, hydraulic load on individual cells was 1 cm/day (1440 L over 144 m^2 per day).

For purposes of computing seasonal values for wetland performance, seasons were assigned months as follows: SPRING = February, March, April; SUMMER- May, June, July; FALL - August, September, October; WINTER - November, December, January. The analysis period for which the following summaries are presented began May 1991 (beginning of Summer season) and ended with May 1994 (end of Spring season). Data from monitoring of the original three parallel wetland cells follows directly. Results that include Cell 4 in series with Cell 1 are detailed in a later section.

Results and Discussion

Measured parameters varied with season and as the system matured. Overall reductions of individual parameters, calculated from mean inflow and outflow measurements over the duration of the study, can be compared using Figure 2. Warm season (summer and fall) and cool season (winter and spring) information is given in Table 1. Average rainfall for the study area is 127 cm/yr. Precipitation was 101 cm the first sampling year (May 1991-May 1992), 132 cm the second year, and 162 cm the third year. Increasing rainfall amounts through the study period could affect interpretations of seasonal and long-term wetland functioning. Individual rainfall events resulted in temporarily increased discharge from the cells, turbulence, and dilution. Fluctuations in rainfall, variability in waste production, and weather conditions also influenced water depth in the anaerobic lagoon.

Inflow rates to the cells for most of the study period were targeted at 1.0 liters per minute. Actual inflows fell between 0.75 and 1.25 L/min at 84% of our sampling visits. As noted in the methods section above, the wetland cells did not discharge continually. There was zero discharge from the system at 43% of visits to the site. Outflow was observed at 103 out of 181 sampling visits (57% frequency). Of these 103 discharge observations, 57 (55%) were at a rate of less than 0.75 L/min, and 83 (81%) at less than 1.25 L/min. Discharges in excess of 1.0 L/min were always associated with rainfall events except during the initial high inflow phase of the project. Average warm season inflow was 1,354 L/day, and warm season outflow was 576 L/day. Average cool season inflow was 1,368 L/day, with outflow of 749 L/day. When no outflow occurred, water samples and measurements were taken after tilting the outflow standpipe until discharge resulted, and the pipe was flushed. This allowed within-cell reduction efficiencies to be calculated without the necessity of outflow.

Table 1. Warm and cool season parameter means and percent difference due to constructed wetland processing.

Warm (W) Cool (C)	Parameter	Units	Influent	Effluent	% Change
W	CBOD5	mg/L	29.99	9.51	68
C	CBOD5	mg/L	31.08	5.07	84
W	COD	mg/L	244	122	50
C	COD	mg/L	343	80	77
W	NH3+NH4-N	mg/L	5.54	1.8	68
C	NH3+NH4-N	mg/L	8.02	1.55	81
W	TOTAL P	mg/L	12.66	7.19	43
C	TOTAL P	mg/L	20.83	7.67	63
W	PO4-P	mg/L	8.59	4.96	42
C	PO4-P	mg/L	11.2	6.4	43
W	TSS	mg/L	128	53	59
C	TSS	mg/L	111	33	70
W	DO	mg/L	2.87	1.43	50
C	DO	mg/L	4.77	2.58	46
W	Fecal Coliforms	No./100 mL	9,970	1,136	89
C	Fecal Coliforms	No./100 mL	19,968	596	97
W	pH	Std. Units	6.86	6.15	9
C	pH	Std. Units	7.2	6.52	9
W	Water Temp.	deg. C	22.46	20.43	9
C	Water Temp.	deg. C	11.23	9.43	16

Temperatures at outflows from the cells were 10.9% lower than at inflow stations because of shading by wetland plants and the shallow depth of water within the wetland cells. This was most evident during winter when outflow water temperatures averaged 21% lower than inflow temperatures. Summer temperature reductions averaged 8%. Inflow station extremes ranged from 5.4 to 30.3° C (mean = 17.8). Outflows ranged from 1.5 to 27.3° C (mean = 15.9).

Conductivity decreased 28.5% with passage through the constructed wetland cells. Greatest reductions occurred during the winter and spring seasons. Reductions increased each year of the study to a peak during spring of 1994 at 44%. Conductivity varied from 28 to 773 µmhos/cm at inflows (mean = 343). Outflow conductivity ranged from 103 to 785 µmhos/cm (mean = 245).

Dissolved oxygen concentrations decreased by nearly half (48.8%) when passed through the wetland cells. Increases were measured only during the initial three months of operation. Reduced oxygen levels were attributable to biochemical oxygen demand, bacterial consumption (and nitrification), and duckweed which quickly colonized open water surface. Measurements during the study period ranged from 0.03 to 14.2 (mean = 3.6) mg/L for inflow stations, and from 0.03 to 7.3 (mean = 1.9) mg/L at outflows in the reducing environment.

A small (9.9%) decrease in pH was observed for water flowing through the wetland cells. Inflow values for pH ranged from 5.7 to 8.5 (mean = 7.0). Outflow values ranged from 5.7 to 7.4 (mean = 6.3). Seasonal reduction percentages for pH were fairly uniform throughout most of the study. Redox potential in the wetland cells increased an average of 137%. Inflow station measurements ranged from (-)259 to (+)311 mV with a mean value of (-)48.39 mV. Outflow measurements ranged from (-)270 to (+)395 mV with a mean of (+)18 mV. Research by Rogers et al. (1991) suggested that increased redox potential in wetland waste treatment systems is due to plant presence, while a decrease in redox occurs in unplanted systems. Though mean values at our site showed an overall increase, values varied widely during the study.

Dissolved solids removal was low (21.8%), while suspended solids removal was relatively high at 60.5%. Total solids were reduced by 31.6% during the three year evaluation (Figure 2). Suspended solids reduction in the wetland cells exhibited distinct seasonal changes linked to plant growth/senescence and plant biomass accumulation/decay. Since much of the suspended solids contained in the waste settled in the lagoon, dissolved solids were the major component entering the wetland. Dissolved solids concentrations during the study varied from 72 to 573 mg/L (mean = 364) at inflow stations, and from 60 to 554 mg/L (mean = 285) at outflows. Suspended solids ranged from 0.0 to 466 mg/L (mean = 122) at inflows and 0.0 to 332 mg/L at outflows (mean = 49). Total solids at inflows) ranged from 176 to 749 mg/L (mean = 484), and at outflows from 149 to 605 mg/L (mean = 331).

Total phosphorus (TP) removal averaged 53.2% for the three year study period. Removal efficiencies climbed from slightly above 50% during the initial season of operation to near 85% after 9 months of system operation. Trap efficiency declined over the next 6 months to 44% removal (summer, 1992). Thereafter, phosphorus removal efficiencies remained moderate. Inflow TP concentrations ranged from a minimum of 1.3 mg/L to a maximum of 69.0 mg/L (mean = 15.9). Outflow concentrations ranged from 0.2 to 22.8 mg/L (mean = 7.4). Principal phosphorus removal mechanisms were probably precipitation and adsorption to sediments. Plant uptake accounted for some removal. If plant removal had been a major uptake mechanism, reduction efficiency would not have declined drastically during the study. Spangle, et al. (1976) found 30 to 66 percent of the total phosphorus in bulrush wetland cells was associated with substrate. Phosphorus is immobilized in organic materials and saturation is reached rapidly (Hammer and Kadlec, 1983). Dolan et al. (1981) discussed phosphorous dynamics in a Florida marsh receiving treated wastewater, and Jones and Lee (1980) evaluated wetlands based phosphorus control for eutrophic waters.

Filterable ortho-phosphorus (FOP) removal efficiency averaged 42.4%, somewhat lower than that for total phosphorus. FOP trapping by the system was near 70% during the initial season of operation and peaked at 85% during the second season. Trapping efficiency declined nearly linearly from that point during the next 12 months to 31% in fall 1992, and averaged 37% afterward. Inflow concentrations varied from 0.9 to 24 mg/L (mean =9.6). Outflows had a low of 0.1 mg/L and high of 15.5 mg/L (mean = 5.5).

Ammonia nitrogen reduction by the wetland system averaged 81.6% overall. Reductions exceeded 90% during the first year of operation, then declined to an average of 81% for the next 5 seasons of the study (summer 1992 through summer 1993). Removal efficiency exceeded 90% again in fall 1993. Reduction then declined to 57% during the next season (winter 1993) and was 65% the final season of the study period (spring 1994). Ammonia nitrogen concentrations entering the wetland cells varied from a low of 0.1 mg/L to a high of 30.8 mg/L (mean = 7.0). Minimum outflowing concentrations reached undetectable levels (<0.01 mg/L) while the maximum outflow concentration measured was 10.8 mg/L (mean = 0.1).

Nitrate nitrogen concentrations entering and leaving the wetland treatment system were low (means = 0.09 and 0.1 mg/L, respectively). Concentrations indicated a net export of nitrate 14.4% higher than inflow, though actual concentrations were nearly negligible. Inflow and outflow concentrations were not expressive of the massive ammonia nitrogen to nitrate nitrogen conversion that occurred within the cells. Export of nitrates was influenced almost totally by that transformation. Seasonal nitrate-N processing began with a 28% average reduction for the first two seasons of treatment, followed by two seasons of 270% export. The system then fluctuated between net reduction and net export during the following 15 months (summer 1992 through summer 1993, averaging 5% reduction overall), before exhibiting > 50% reduction in nitrate-N for the last three seasons of the study (fall 1993 through spring 1994). Inflow nitrate nitrogen ranged from undetectable (<0.01 mg/L) to 0.9 mg/L. Outflow concentrations also ranged from undetectable levels to 3.3 mg/L.

Five-day carbonaceous biochemical oxygen demand (BOD_5) was reduced consistently by about 80% following the first season of operation in which there was only a 42% reduction (overall 74.6% reduction). BOD for inflow stations averaged 35.1 mg/L (minimum = 9.7, maximum = 80), while outflow stations averaged only 8.9 mg/L (minimum = 0.3, maximum = 48).

Total chlorophyll was also reduced by about 75% (78.8%), though with more seasonal fluctuation than seen for BOD. Mean inflow concentration was 306 mg/L, with a minimum of <0.01 and a maximum of 1,505 mg/L total chlorophyll. Outflows had a mean of 64 mg/L, a minimum of 1 mg/L and a maximum of 759 mg/L. Inflowing chlorophyll was reduced because of settling and flocculation. In-cell production was minimal because of plant shading.

Coliform bacteria were abundant in pre-treatment lagoon wastewater; yet our data showed there was an 89% reduction in total coliforms with passage through the wetland cells. Inflow concentrations had a mean of 14,525 colony forming units (CFU)/100 ml, with a minimum of 40 and a maximum of 101,000 CFU/100 ml. Outflow mean concentration was 1,585 CFU/100 ml, with a minimum observed of 20 and a maximum of 19,700 CFU/100 ml. (This information excludes individual tests where sample dilution resulted in extinction of coliform bacteria and resultant lack of colony forming units.)

Chemical oxygen demand, the oxygen equivalent of the organic matter that can be oxidized by a strong chemical oxidant, was measured on a quarterly schedule. Average inflow demand was 263 mg/L, while outflow demand was only 96 mg/L, resulting in a mean reduction in COD of 63% with passage through the wetland cells.

Results from Addition of Cell 4

A single additional cell of the same dimensions as an original cell was added in series to Cell 1 during Summer 1991 (Fig. 1). This cell, Cell 4, received effluent from Cell 1 only, and served as an experimental polishing cell. The cell was planted in Spring 1992 (late April /early May) with rhizome cuttings at one meter intervals. By early June, 1992, plantings had expanded as healthy spreading clumps. By early August they formed a nearly continuous stand within the cell.

When compared to mean changes of parameters in the original three cells, Cell 4, acting as an additional treatment cell, produced the following notable changes in water quality. Conductivity produced an added 23% reduction for a total reduction of over 51% from inflow values at Cell 1. Dissolved oxygen concentrations in Cell 4 increased relative to Cell 1 outflow, yet did not equal concentrations entering the wetland cells from the lagoon. This increase in oxygen resulted in an overall 28% reduction of DO, as opposed to a 48% average reduction that occurred in the three original cells. Likewise, pH values increased as water flowed through Cell 4, as opposed to a decrease in the original cells, but again not reaching original inflow values (5% decrease with Cell 4 included vs. 10% average decrease in original cells alone). Total solids decreased an additional 20%, for a total reduction of >51% because of dissolved solids trapping. There was little change in suspended solids concentrations in Cell 4.

Filterable ortho-phosphorus concentrations declined an added 37%, and total phosphorus declined an additional 23% in Cell 4. This added trapping was similar to initial phosphorus trapping in the first three cells. Ammonia-nitrogen concentrations

declined an additional 13% over the average original cell reduction of 82%.
Nitrate-nitrogen concentrations at outflow from Cell 4 were 52% lower than inflow at Cell 1, negating the increase of nitrate-nitrogen observed in the original cells (though, again, actual concentrations were very low, with mean values of 0.10 mg/L or less for all inflow and outflow stations).
Total chlorophyll concentrations and BOD were 9% less when Cell 4 was used.
Coliform bacteria concentrations were relatively unchanged.

Observations and Recommendations

A. Biomass Removal: Bulrush vegetative growth generally matted after senescence. In many cases mats assisted in forming anaerobic conditions and were impenetrable, preventing renewed spring growth. Harvesting of biomass enhanced growth in Cell 1 and eliminated the matting problem for the short term. However, bulrushes should not be recommended unless some harvesting method is planned. An annual harvest would also reduce the phosphorus which is temporarily bound in plants. Natural wetland studies reveal seasonal export of phosphorus in spring after plant material decays (Spangle, et al., 1976). Our study exhibited a decline in total phosphorus trapping each spring. Spangle, et al. (1976) also found that a single fall harvest netted greater biomass than several periodic cuttings over the growth season. Gersberg, et a1.(1983) recommended annual harvest for improved cell productivity. They also mulched wetlands to add carbon to assist in nitrogen removal. With some species such as cattails, burning excess biomass during the simulated dry part of a hydro period may be feasible.

B. Plant spacing: Some authors (Gearheart, 1992) recommend high initial planting density. We initially used a 0.3 m setting on staggered rows for our first plantings. When we planted our 4th cell and replanted bare spots, we used a 1.0 m setting on staggered rows. The 1.0 m setting was satisfactory with *Scirpus validus* because of vigorous rhizome growth.

C. In-cell processing and cell dimensions: Results showed that some contaminants were processed in a linear fashion and that processing was dependent upon cell length. Processing for others was mainly in the first third of the cell. Cell design should be targeted for principal contaminants, and cell size should depend on the worst case processing efficiency. Over designing cells so that outflow is not continuous but is seasonal allows for some resemblance of a natural wetland hydro period.

D. Maintenance: Properly designed inflow/outflow piping requires routine flushing. Levee maintenance is essential. Multiple cells are highly desired so that a single cell can be isolated for maintenance. With bulrushes, plant biomass becomes a significant problem within three years. Plants must be harvested or biomass otherwise removed. We conducted two biomass removals. Both exhibited some degree of success although each had difficulties. Mechanical removal of dead material successfully allowed new shoots to sprout, but it was labor intensive. We also drained one cell and burned dead material. This method required constructing a sump and pumping water from the cell for 4 days.

Burning may be more successful with species like cattails which produce clumpy, easily burnable biomass.

E. Cost: Constructed wetlands represent a low initial cost/low maintenance method for treating some animal wastes.

Conclusions

Three parallel wetland cells, planted to giant bulrush, were evaluated for 36 months while receiving wastewater via a primary settling lagoon from a <100 cow dairy operation. Results from these three original cells showed best reductions in coliforms, BOD, chlorophyll and ammonia nitrogen, the potential contaminants of concern. Study length allowed for some evaluation of cell maturation. Initial phosphorus and nitrogen processing was quite high. However, when cells became loaded with these nutrients, efficiencies stabilized at lower rates. Seasonal variations were evident, but cells were functional continuously. Effectively doubling the cell length by adding a fourth cell allowed for 24 months of additional comparison. Greatest changes from additional length were in nutrient removal and dissolved oxygen improvement. Cell size should be based on most effective treatment of targeted contaminants. The major negative factor associated with bulrushes was build up of biomass. Removal of decaying biomass was essential for annual plant emergence from rhizomes. Constructed wetland cells represent an alternate method of processing some agricultural wastes, but, as our study showed, individual cell variability and seasonal/long-term trends make operation challenging.

Acknowledgments

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Essex Treatment Wetland, Essex, Ontario, Canada

Paul Hermans and John Pries*

Background

The Essex treatment wetland was constructed on the Malder Valley farm in fall 1993 to treat barnyard runoff and milkhouse washwater wastes from a dairy operation. It is one of seven sites in Ontario where research is being conducted to determine the feasibility and treatment effectiveness of constructed wetlands for reducing contaminants in high strength wastewater from animal operations. At the same time, these projects will evaluate the effectiveness of dissipating the water through natural processes such as evaporation and transpiration without discharging offsite. Four of the systems, including the system in Essex, were constructed using similar designs to allow for easier comparison of the monitoring and performance data. The Essex design consists of a holding pond (see Figure 1) followed by a serpentine wetland treatment cell that discharges into a final holding pond. Capital and operating costs and system maintenance requirements are being tracked over time. Source controls to reduce the contaminant loading to the treatment wetland include a covered manure storage that was constructed to reduce rainwater runoff from the manure and an exercise yard that was paved and curbed with concrete and sloped to drain to a central catch basin.

Treatment Wetland Design

Before installing the Essex treatment wetland, all liquids drained off the barnyard facility directly to Woltz Creek. The milkhouse wastewater entered the creek through a tile drain. Barnyard runoff and approximately 200 gallons per day of milkhouse washwater are directed to a sump and then pumped to a 50,000 cubic foot (ft^3) sedimentation basin/facultative pond. The pond was designed to pretreat the wastewater by providing anaerobic conditions and allowing solids to settle, thus reducing the solids, BOD_5, nitrogen, and total phosphorus loading to the wetland. It also provides storage during the nondischarge period of approximately 6 months. The pond was sized for a 100-year storm combined with washwater produced on a daily basis. Removal of sediment from the pond is possible when required with standard liquid manure handling equipment or a backhoe.

The single wetland cell at the Malder Valley farm has a surface area of about 600 m^2 (0.15 ac) and is serpentine in shape with an aspect ratio of about 24:1. During the growing season, stored wastewater is discharged at a controlled rate to the wetland cell using an inground weir structure. This weir also controls the liquid level in the sedimentation basin. The wastewater flows through shallow zones vegetated with cattail (*Typha latifolia*), water plantain *(Alisma triviale*), arrowhead (*Sagittaria latifolia*), flowering rush (*Butomus unbellatus*), softstem bulrush (*Scirpus validus*), and duckweed (*Lemna* spp.) that are separated by deep zones vegetated with duckweed, bur-reed (*Sparganium eurycarpum*), hornwort (*Ceratophyllum demersum*), and sedge (*Carex* spp.). The vegetation was trans-

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planted to the wetland cell from road-side ditches in spring 1994. Monitoring equipment was installed in fall 1993 and spring 1994.

The treated effluent discharges to a polishing pond for final treatment. Water loss from the final pond is due, in part, to evapotranspiration. There is a net precipitation gain in Ontario, and the system will likely have some discharge during part of the year. The wetland is designed with additional freeboard capacity in the event of a severe rainstorm. If the wetland cannot handle a major rain event or the final holding pond is filled to capacity during the rainy season, the treated water is spray irrigated onto a grassed waterway located in the farmer's pasture. If these systems are proven to be effective for the removal of contaminants and are cost-effective, the Ontario Ministry of the Environment and Energy (MOEE) may require a certificate of approval under the Water Resources Act to permit discharge into a watercourse. A plan view of this system can be seen in Figure 1.

A clay soil overburden at the site negated the requirement for a liner. After excavation, the native soil was compacted to reduce the potential for the wastewater percolating into the subsoil.

Wildlife

Wetland wildlife observed during summer 1994 include insects such as predaceous diving beetle larvae, adult dragonflies and damselflies, water boatmen, dragonfly and damselfly larvae, backswimmers, midges, riffle beetles, and whirligig beetles; amphibians including the young of the year American toads; and mammals including muskrats. The muskrats severely damaged the wetland vegetation in the first year, and their burrowing activities caused short-circuiting between sections of the serpentine wetland path. Muskrats have been controlled by trapping them and by reducing the wetland water level in the fall (to expose the entrance to the muskrat home) and maintaining the low water level during winter.

Project Involvement

This project was a cooperative effort. The landowner provided the property, partial capital funding, and has the responsibility for the ongoing maintenance. The Essex Region Conservation Authority designed the treatment wetland system, oversaw the construction, implemented the monitoring program, coordinates the research, and provided materials for and installed the monitoring equipment. Funding for the wetland construction was provided by Agriculture Canada's Rural Conservation Clubs Program and Harrow Research Station Environmental Assessment Review. The MOEE provided technical support for the data logger monitoring, staff gauges, rain gauge, and redox meter. The covered manure storage was funded through the MOEE program Clean Up Rural Beaches (CURB), and Canada Trust funded the groundwater monitoring equipment (water level meter, supplies, and materials for seven piezometers). Ontario Ministry of Agriculture and Food (OMAF) provided support for the groundwater investigations. Centralia College funded and conducted a soils and groundwater assessment.

The Association of Conservation Authorities of Ontario provided a facilitation/research role among the various partners to establish treatment wetlands in several Ontario Regions. The association was also actively involved in the design and construction supervision of the systems and are currently monitoring the systems.

In January 1996, the funding for these projects was severely cut in many locations. In the future, these projects may not receive the level of effort required to continue to gather long-term monitoring data as these systems mature. The project managers believe that tracking these systems is extremely important, and they are searching for innovative sources of funding and analytical support that will allow them to continue to collect performance data.

Monitoring Program

An intensive monitoring program is underway with dataloggers recording water levels in the storage pond and wetland, water and ground temperatures, and rainfall; and frequent sampling of the water quality throughout the treatment wetland system. A total of four deep piezometers and three shallow piezometers were installed around the site to monitor potential groundwater contamination. Sampling frequency for groundwater monitoring is one sample per sampling location during each of the months of January, April, July, and October. Results of the groundwater samples collected to date have not been reported.

Operational performance

Table 1 summarizes monitoring data collected during the first 9 months of operation, April to December 1994. Monitoring data from May to November 1995 are presented in Table 2. The data are typical of early operating results reported by others.

Future Direction

The Essex Region Conservation Authority will be completing a summary report of the Essex project in 1997. Each of the Conservation Authorities involved in a treatment wetland will prepare similar summary reports of their treatment wetland systems. A committee has been established to secure further funding for long-term data collection, summarize the effectiveness of the Ontario systems, consider the applicability of treatment wetlands for high strength livestock wastewater, and recommend improvements for future installations. The committee, called the Agriculture Wastewater Treatment Group, is made up of the Conservation Authority representatives and the Ontario Ministry of the Environment and Energy.

Conclusion

The Essex treatment wetland system has significantly reduced the contaminant loading from the farm to Woltz Creek. The Conservation Authority and the Ontario Ministry of the Environment and Energy are aware of the potential this treatment technology provides to the livestock farming community and are committed to further research. The owner of the farm has seen the positive environmental effects of the treatment wetland and has become a strong proponent of this technology to friends, neighbors, and the news media.

Table 1. Treatment wetland monitoring data for a dairy in Exxex, Ontario, Canada; April to December, 1994.

Parameter	Units	Avg. wetland inflow concentration	Avg. wetland outflow concentration	% concentration reduction
BOD_5	mg/L	357	202	43
TSS	mg/L	1,596	48	97
NO_3-N	mg/L	0.19	0.12	37
TKN	mg/L	119	17.5	85
TP	mg/L	25	3.9	84
Dissolved P	mg/L	11.5	2.3	80
Conductivity	μmhos/cm^2	3,091	1,225	60
Chloride	mg/L	293	182.5	38
Fecal coliforms	No./100 mL	1,030,000	11,999	99
E. coli	No./100 mL	220,600	11,343	95

Table 2. Treatment wetland monitoring data for a dairy in Exxex, Ontario, Canada; Geometric mean concentrations for May to November 1995.

Parameter	Units	Transfer pump to storage pond	Wetland inflow concentration	Wetland outflow concentration	% Concentration reduction
BOD_5	mg/L	487	68	26	62
NH_3-N	mg/L	50	12	2.4	80
Total PO_4	mg/L	26	12	3.7	69
TSS	mg/L	332	151	104	66
E. coli	No./100 mL	149,267	1,208	409	66

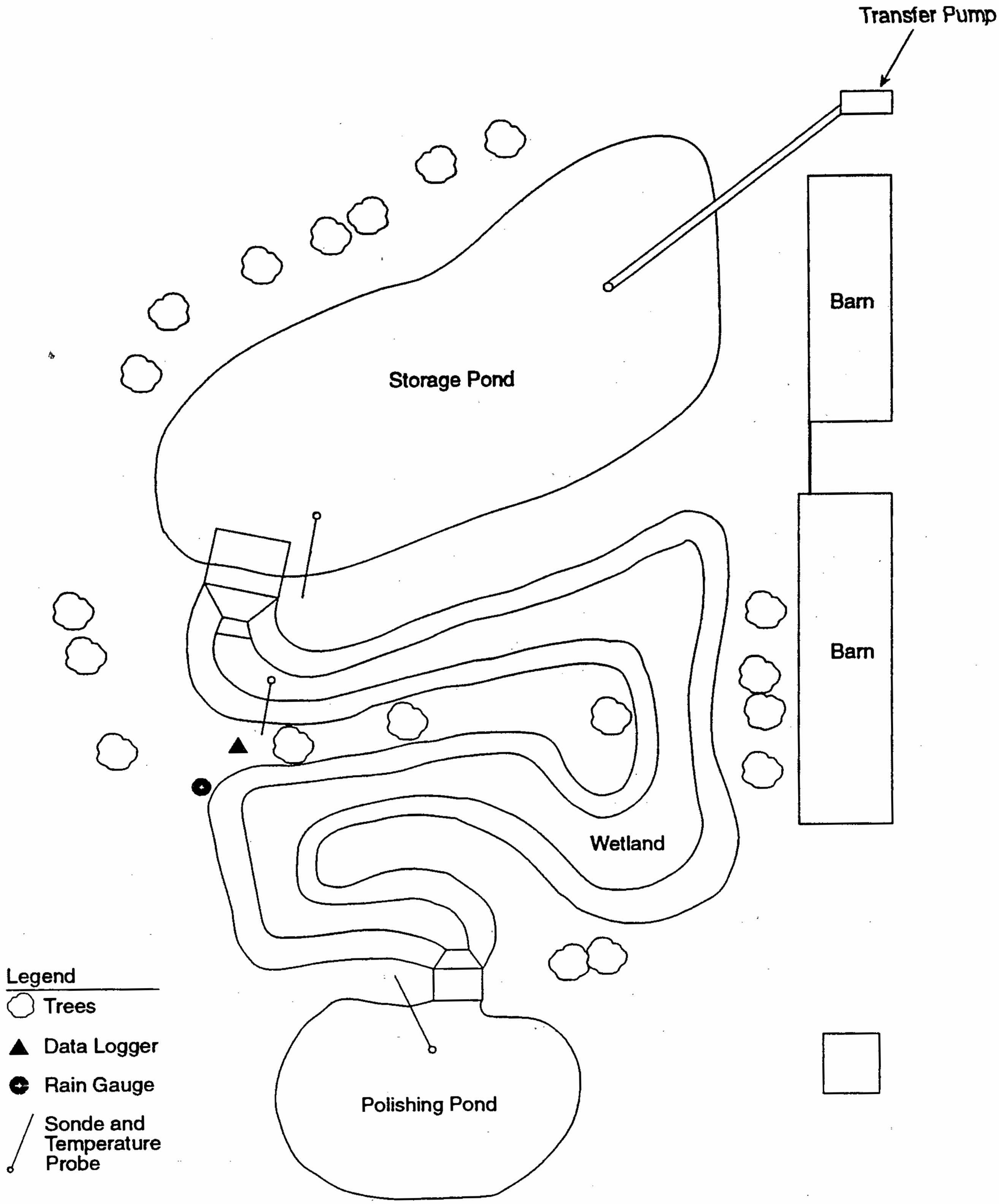

Figure 1: Plan View of Essex Treatment Wetland System

Oregon State University Dairy Wetland

James A. Moore, PhD. and Steven F. Niswander*

Background

Six wetland ponds were constructed at the Oregon State University campus dairy and began receiving wastewater in the fall of 1993. All of the ponds were loaded at the same rate with diluted dairy wastewater. This diluted wastewater was still "high" strength, with biochemical oxygen demand and ammonia concentrations of approximately 700 and 130 mg/L, respectively. This is much higher than recommended loading rates for domestic wastewater (US EPA, 1988). However, we were interested in looking at the highest mass removal we could achieve. This would then reduce the amount of manure nutrients that would have to be land applied. This objective is slightly different than most domestic wastewater wetlands that are designed to achieve some minimum outlet concentration. Samples of the influent and effluent were collected from all wetland cells twice a month. Analyses of thirteen water quality parameters were conducted. These included chemical oxygen demand, biochemical oxygen demand, total solids, total suspended solids, total phosphorus, orthophosphorus, total Kjeldahl nitrogen, ammonia, fecal coliforms, pH, conductivity, dissolved oxygen, and temperature.

Site description

The Animal Sciences Department at the Oregon State University campus operates a working dairy with 140 mature milking cows and an accompanying complement of young stock and calves. The manure is handled with a recycling flush system. The solids are removed using a stationary screen separator, and the liquid manure is held in an above ground storage tank. A second smaller storage tank is used for dilution of the wastewater before pumping it to the six wetland cells (Figure 1). The ponds were loaded at approximately 3.9 cm/day (1.5 in/day) to achieve a 7.7 day retention time.

Each wetland cell is 26.7 m (87.6 ft) long, 5.5 m (18 ft) wide, and 0.3 m (1 ft) deep. Cells 4 and 9 have deep (1 m) center sections while the others have a flat bottom, sloping 0.5% toward the outlet (Fig. 1). Two treatment cells were planted with cattail (*Typha latifolia*) and four were planted with hardstem bulrush (*Scirpus acutus*) in 1992 as shown in Table 2. Nursery rhizome stock was planted in a 1.0 x 0.6 m (3.3 x 2.0 ft)

Table 2. Principal types of vegetation in each of the cells.

Cell Number	Type plants
4	Cattail
5	Cattail/grass
6	Bulrush/grass/cattails
7	Grass
8	Bulrush/other species
9	Bulrush

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pattern. After the plants were established and the pond filled, nutria (*Myocaster coypus*) destroyed most of the plants. A welded wire fence and electric fence wire were constructed around the research site to limit nutria access. The ponds were than replanted in the spring of 1993. There has been no noticeable damage from nutria since the installation of the fence. By the fall of 1994, most of the ponds had become a mix of original species and invader species (Table 2).

The wetland cells are constructed in an area with Amity silty clay and Bashaw clay loam soils. Soil depth averages 60 cm (24 in) throughout the site. Soil profiles show a poorly drained mottled clay layer at 60 cm (24 in). Cell bottoms are just above the surface of this clay layer, except for the center sections of cells 4 and 9, where the deep sections enter about 60 cm of the clay layer. Topsoil was not used in the bottom of cells as the Amity and Bashaw soils were adequate for establishing wetland plants. Bottoms of cells are compacted Bashaw clay with an estimated hydraulic conductivity of less than 1×10^{-7} m/sec. The above ground and above water level berms are compacted Amity soil with a conductivity of 1×10^{-6} m/sec, which is within the recommended conductivity for wetland systems (US EPA, 1988).

Results and Conclusions

The wetland reduced the concentrations of all parameters by an average of 65%. The lowest reduction was 48% for both total phosphorus and ammonia. The greatest reduction was 94% for fecal coliforms. Table 3 is a summary of the average percent reductions for all of the parameters.

The deep center sections in ponds 4 and 9 did not show any significant impact on the treatment efficiency of the water quality parameters evaluated. While treatment differs by plant species, the treatment differences in wetland cells with mixed plant populations appears to be small.

The phosphorus removal needs to be studied for a longer time to confirm long term removals. The constructed wetlands at the Oregon State University dairy also appeared to be oxygen limited (Niswander et al., 1996). The wetland cells are currently being loaded at a much lower loading rate, which does not deplete all of the oxygen. The retention times have also been varied to find the optimum retention times for achieving the lowest outlet concentrations. This information along with our previous findings will allow us to make recommendations on the optimum loading rates and retention times for achieving both the maximum mass removal and the lowest outlet concentrations.

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Table 2. Estimate of percentage cover by each species October 4, 1994.

Pond Number	*Typha latifolia*	Scirpus acutus	Grass*	*Hydrocotyl ranunculoides*	*Lemna spp.*
4	30	5	20	0	45
5	30	10	60	0	0
6	30	20	50	0	0
7	10	5	80	0	5
8	35	20	5	30	10
9	0	20	5	0	75

**Glyceria occidentalis* and *Alopecurus geniculatus.* (Both species appeared floating.)

Table 3. Summary or dairy data.

Parameter	Inlet	Outlet	% Reduction
BOD_5 (mg/L)	705	242	66
COD (mg/L)	1,628	655	60
Total solids (mg/L)	1,195	852	61
TSS (mg/L)	542	142	74
TP (mg/L)	33	17	48
Ortho-P (mg/L)	167	86	49
NH_3+NH_4-N (mg/L)	126	65	48
D.O. (mg/L)	1.08	0.23	94
Conductivity (µmhos/cm^2)	2,279	1,644	---
Temperature (°C)	10.6	9.3	---
pH (std. units)	7.5	7.1	---

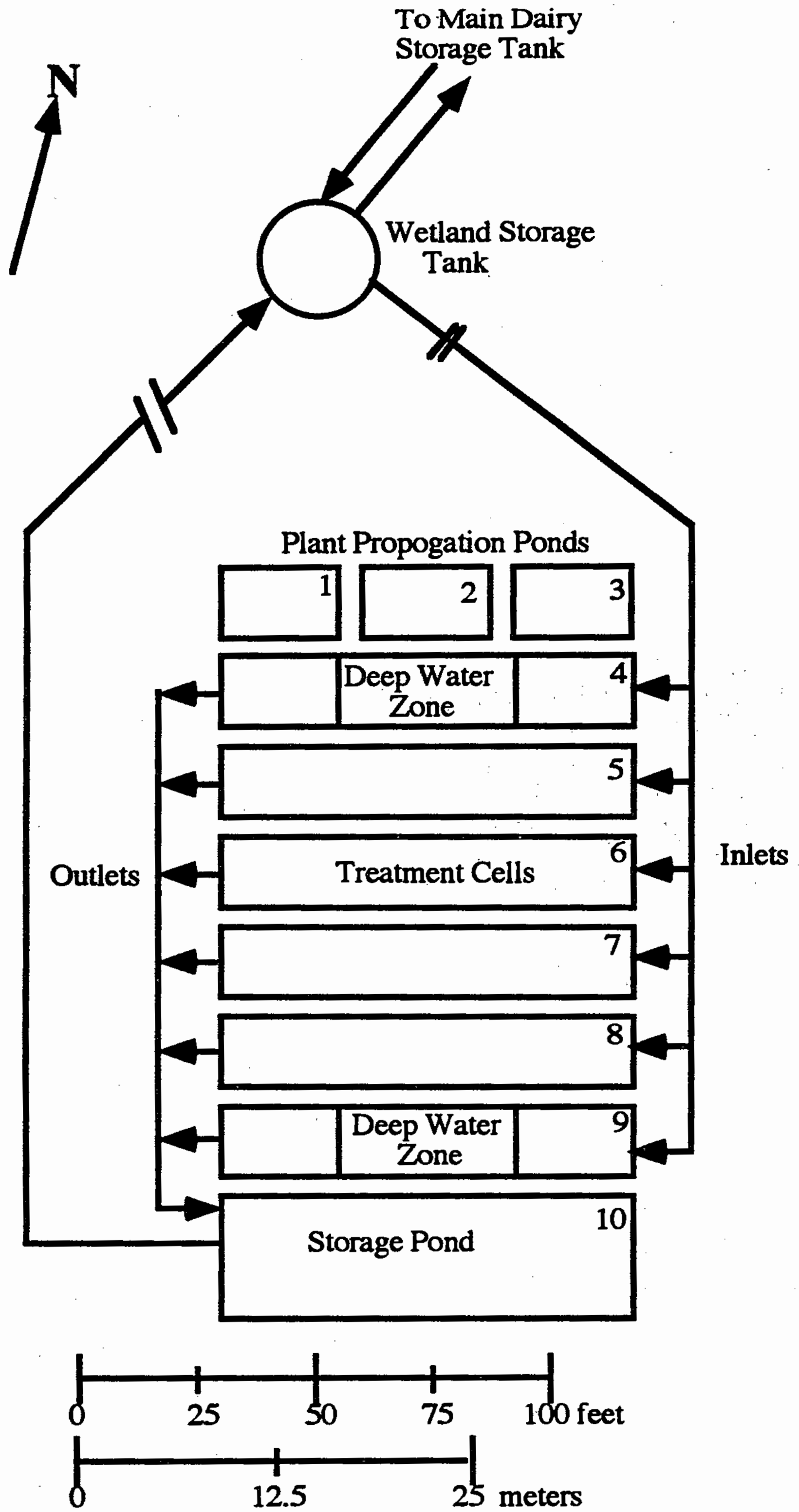


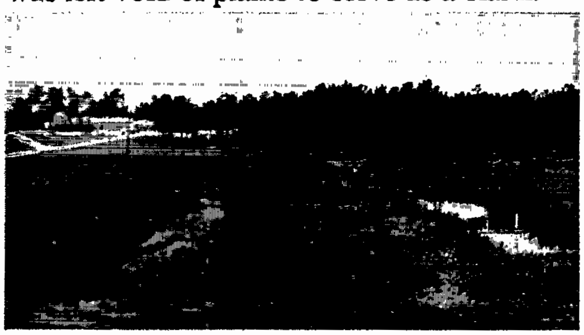
Figure 1. Site map of Oregon State University dairy wetland research site.

Auburn University Constructed Wetlands for the Treatment of Poultry Lagoon Effluent - A Case Study

D.T. Hill and J.W. Rogers*

Introduction

Three series of dual cell free-water-surface constructed wetlands were installed at the Poultry Unit of the Alabama Agricultural Experiment Station in Auburn, Alabama, during the summer of 1992. The first two series of cells were vegetated while the third was left void of plants to serve as a blank.



Two pair of cells were vegetated and one pair served as a control (far right in photo).

Each cell was 5.5 m wide, 10.5 m long and 1 m in depth. During construction, clay was brought in to line the bottom of the cells to reduce seepage. The constructed wetlands were supplied water from the three lagoon wastewater treatment System at the Poultry Unit (Figure 1). Valves were located between the third lagoon and the wetlands to allow a choice of wastewater from the first or third lagoon.

On October 15, 1992, the first shipment of plants arrived. *Sagittaria lancifolia* was sprigged in Series 1 and *Phragmites australis* was sprigged in Series 2. Wastewater from the third lagoon was then applied to maintain a water depth of 7.5 cm. During the winter of 1992-93 all of the plants perished due to the lateness of planting and the extremely cold weather in January. In early April, Series 1 and 2 were completely replanted. Series 1 once again received *Sagittaria lancifolia* and Series 2 received *Scirpus* spp. in addition to the *Phragmites australis*. Water was supplied from the third lagoon to maintain a depth of 10 cm. The water level was gradually raised to 30 cm near the end of May. In mid-July the influent source was changed to the first lagoon to provide a heavier nutrient loading.

In addition to the three large wetlands, two series of scaled down "model" wetlands were constructed in the first blank cell. Each cell of the model wetlands measured 0.6 m wide, 3.4 m long and 0.3 m deep. Wooden dowel rods, 1.2 cm in diameter and 40cm in length, were driven into the clay soil to provide an inert growth medium. One series of the model ponds received 5% (by volume) dowel fill and the second received a 10% fill. The effluent from these model ponds was piped to the influent of the second blank cell. Table 1 shows the fill rates for plants and dowels in the respective cells or series.

Soil water lysimeters were installed in the first and second cells of the first three series at depths of 0.6 m and 1.3 m to monitor the concentration of chemical parameters present in the soil percolate. The lysimeters were constructed of a white PVC tube with an outside diameter of 4.8 cm and lengths of 1.2

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Table 1. Cell series with type of plants or dowels and percent fill in each.

Series No.	Plant or dowels	% fill with plants or dowels
1	*Sagittaria*	~10
2	*Sagittaria* + *Phagmites*	~5
3	Blank	0
4	Dowels	~10
5	Dowels	~5

m or 1.8 m. A porous ceramic cup was attached to the bottom end of the PVC pipe. Lysimeter samples were collected once a month beginning August 6, 1993.

Beginning August 6, 1993, wastewater samples were collected twice a month until March 9, 1994. A 500 ml grab sample was taken from the influent stream of the five series. A 500 ml sample was also taken from the effluent of each of the five series. COD and BOD_5 analyses were performed by *Standard Methods for the Examination of Water and Wastewater* (APHA, 1992). TKN and NH_4 analyses were performed according to the methods of AOAC (1984).

Results and Discussion

This study was initially scheduled to run from August 1993 until June 1994 to investigate the potential for treating dilute poultry waste as well as the variation in treatment levels during the winter months. Due to an instability in the supply of wastewater to the wetlands, it was involuntarily halted on March 9, 1994. The data that were collected should provide necessary information for a preliminary investigation of changes in the treatment levels due to seasonal variations. It should be noted that the poultry research unit added considerably more water than would be used by the typical poultry producer. In addition, some spring water was seeping into the lagoons. For these reasons, the lagoon wastewater was much more dilute than that of most poultry lagoons.

All series of wetlands were operated at a constant depth of 30 cm during the period of the study. A constant hydraulic loading rate of 3.1 cm/day was applied to each series of wetlands. This resulted in a COD and TKN loading rate of 145 and 30 kg/ha-day respectively. In order to determine detention time and also to validate the plant fill, a water column displacement test, where the volume of water present in a column of the pond is determined and compared to the theoretical volume had the plants not been there, was performed on the vegetated Series 1 and 2. The expected values of 10% and 5% were surprisingly close to the measured values of 10.7% and 6.7% for Series 1 and 2, respectively. The detention time was calculated to range from 11.1 to 11.6 days in the three series.

Examining the data in Table 2, it is evident that constructed wetlands are capable of treating dilute poultry waste. The vegetated series (Series 1 and 2) provided better treatment than the dowel series (Series 4 and 5). Series 3, the blank, performed equivalent to the vegetated series in all aspects except COD removal.

The initial expectation was for the vegetated series to outperform the blank. This however did not happen. It is believed that the age of

Table 2. Removal efficiencies (%) during the entire study period.

Series No.	BOD_5	COD	TKN	NH_4	PO_4	K
1	49.8	60.7	42.8	37.6	36.8	28.4
2	45.7	61.5	56.7	52.8	34.0	12.4
3	48.5	54.3	45.7	44.3	36.7	8.8
4	30.2	28.0	20.3	19.9	8.0	14.5
5	35.2	39.8	27.1	26.4	20.4	22.3

the system is responsible for this. Like most biological systems, constructed wetlands require a period of time to become established. Litter and stems within the column form emersed solid surfaces which enhance bacterial growth. According to Kadlec and Knight (1996), the biological activity on these surfaces represents the principle mechanism for treatment within the constructed wetland.

Thus, the immature system that was the subject of this study had a relatively undeveloped "biofilm" which is needed to provide high levels of treatment. Treatment levels should increase as the constructed wetlands get older and the plants and litter spread to fill in void areas. As the system matures, microbiological activity and, thus, treatment efficiency, will increase. The system which served as the blank series is a much less complex aerobic to facultative system containing algae and suspended microorganisms. Since algae are fast growing, a system such as the blank should yield better treatment sooner after establishment.

To investigate the difference in treatment levels, the total study period was broken down into five seasonal periods. The first period began August 1 and ended October 31, 1993. This period is representative of the warm season. November 1 started the cool period with the first hard frost that killed the vegetation above the water line. Period 2 was defined as beginning November 1 and ending December 1. During this period it was too cold for continuous plant growth but warm enough during most days (i.e., water temperature > 10° C) to sustain bacterial growth. The third period, referred to as the cold period, started December 2 and ended February 3. During this period the average water temperature was below 10° C. The fourth period began February 4 and continued until March 9 when the project was halted due to the interruption in the influent wastewater supply. This fourth period represented the recovery stage when the water temperature rose above 10° C, yet plant growth had not restarted. A fifth period was planned to continue until June when the water was warm and the plants were growing. However, due to wastewater supply problems only the first four periods were completed.

Examining Figures 2 and 3, graphical representations of COD and BOD_5 reductions for the four study periods, it is clear that the ponds containing plants provided better treatment than the dowel or blank series. This strongly suggests that live wetland plants provide some manner of growth enhancement in the bacteria responsible for the removal of organic matter. Period 2 produced mixed results with regard to COD and BOD_5 reductions. Series 1 had a slight increase in treatment efficiency while Series 3 showed a dramatic increase from 50% to 70%. Series 2, 4 and 5 showed decreases in treatment performance. As the temperature decreased during period 2, microbial activity should have slightly decreased causing treatment to also decrease. If the plants played an active part in the treatment process, the decrease in the treatment levels in the vegetated series should have declined more after the first frost than the dowel rod series. Series 2 (5% plants) did drop in performance. Series 1 (10% plants) slightly increased in performance. This series contained *Sagittaria* which was killed back immediately following the first frost. However, the plants did start growing back until the next frost killed them again. This cycle of growth and die-back continued until the middle of December when complete death occurred. It is possible that these plants continued to play a role in the treatment process while re-growing.

The treatment in the dowel series also decreased during the third period. The 10% fill series suffered a larger decrease than the 5% fill series. This would be expected since the 10% series contained a larger population of microorganisms due to the amount of media surface area present. As the water temperature decreased, more bacteria were present to slough off in Series 4 causing a higher organic loading than in Series 5.

Period 4 provided some interesting results as the COD removal increased slightly in the vegetated series. In the dowel rods, however, treatment levels increased greatly from 8.2% to 28.9% and 37.9% to 52.6% for Series 4 and 5 respectively. The BOD_5 removal was different. BOD removal dropped sharply in Series 1 and 2 while Series 4 and 5 showed dramatic increases in treatment levels. It is possible that as the water began to warm, dead plant material present in Series 1 and 2 began decomposing adding an additional organic load to the system. Also, the dowel rods continued to present a solid attachment site while the decomposing plants resulted in a loss of attachment sites.

The TKN and NH_4 removal data shown in Figures 4 and 5 revealed few surprises. Once again the vegetated and blank series provided better treatment during the first periods. During the fourth period, the TKN and NH_4 removal dropped in Series 1, 2 and 3. The decrease in organic removal during this period suggests a low oxygen content which could also inhibit the nitrification process and significantly decrease nitrogen removal through the nitrification-denitrification pathway. The performance of the dowel series showed a large increase, possibly due to a solid point of attachment which the plants could not offer.

The concentration data for the chemical parameters in the lysimeter samples are contained in Table 3 and most were within acceptable ranges with no cause for alarm, except the NO_3 levels. High nitrate concentrations may cause the health problem methemoglobinemia, better known as bluebaby syndrome. The phosphorus concentration in the lysimeter samples did not differ statistically among the different depths or cells. Series 1 was statistically different than Series 2 and 3. The difference, however, was very small (<0.5 mg/L and could have been due to the plant species or variation in initial soil concentrations.

Examining the nitrogen parameters in the lysimeter samples, several interesting trends are noted. Series 3 had significantly higher average concentrations of TKN than Series 1 or 2. This was expected since the wetland plants provide oxygen to the root zone, thus promoting nitrification. The NO_3 concentration also varied with plant volume. Series 1, containing 10% plants, had a mean NO_3 concentration of 21.1 mg/L-N while Series 2, containing 5% plants, had a lower concentration of 14.9 mg/L-N. Series 3, the blank cells without any plants, had the lowest concentration of NO_3 at 12.2 mg/L-N. TKN also showed a significant decrease going from the 0.6 m depth to the 1.3 m depth in Series 2 and 3. There were also no significant differences for the nitrogen parameters between the first and second cells in each series.

Conclusions

It should be stated that as constructed wetlands are biological systems, a period of time is required for the ponds to become fully established. In previous research by DeJong (1976), starting effects were found to be present until the third year of operation. Due to funding restraints, this study had to take place the first year the wetlands became operational. However, these preliminary conclusions shall be the basis of future research at this site.

These constructed wetlands have shown the capability of providing treatment to dilute poultry wastewater within the first year of operation. BOD_5 removal was almost 50%, while COD removal varied from 40% to 50%. Overall, the treatment levels in the vegetated series were not much greater than in the blank series. However, the vegetated systems should show increased levels of treatment as they become better established.

The effect of plant presence on wastewater treatment during the cold winter months was difficult to determine due to the variation of the influent quality. The most obvious effect occurred in the early spring when the temperature began to rise. During this time, the treatment provided by the vegetated series decreased while treatment in the dowel series increased. This is believed to be caused by the decomposition of dead plant material which might drive the system into an anaerobic state, therefore hurting performance. This suggests that the harvesting of the plants during the winter months may improve the quality of the effluent from this type of system.

The lysimeter data raises concerns about the levels of nitrates present in the groundwater below these systems. Further studies should be conducted to determine if this is a site specific problem or a problem inherent with this design of wetlands systems.

References

AOAC (1984); Official Methods of Analysis; Association of Official Analytical Chemists. New York.

APHA (1992); Standard Methods for the Examination of Water and Wastewater; American Public Health Association, Washington, DC, 18th edition.

DeJong, J. (1976); *The purification of wastewater with the aid of rush or reed ponds*; In Biological Control of Water Pollution, ed. Joachim Tourbier and Robert W. Pierson; University of Pennsylvania Press, Inc.

Kadlec, R. H. and R. L. Knight (1996); Treatment Wetlands; Lewis Publishers. Boca Raton, FL.

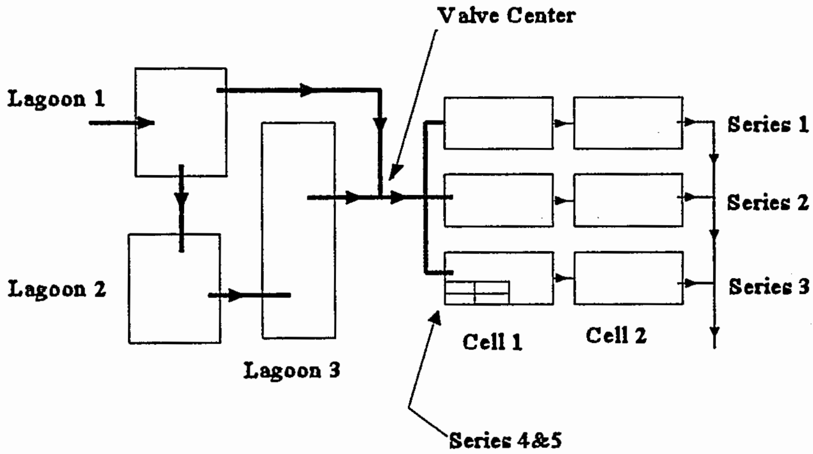


Figure 1. Overview of lagoon and constructed wetland treatment systems.

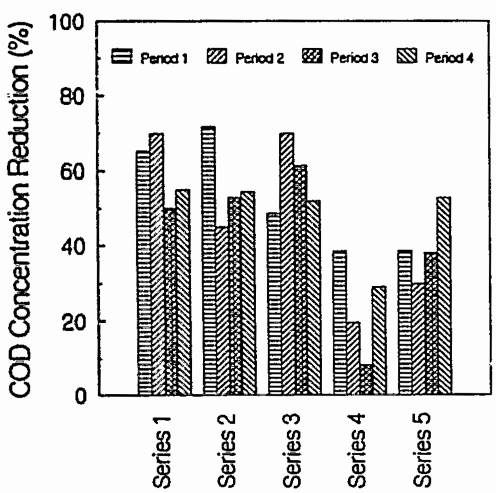


Figure 2. COD removal in each series during the four periods.

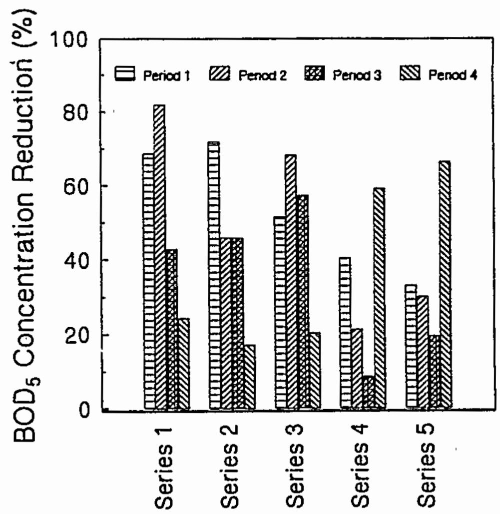


Figure 3. BOD_5 removal in each series during the four periods.

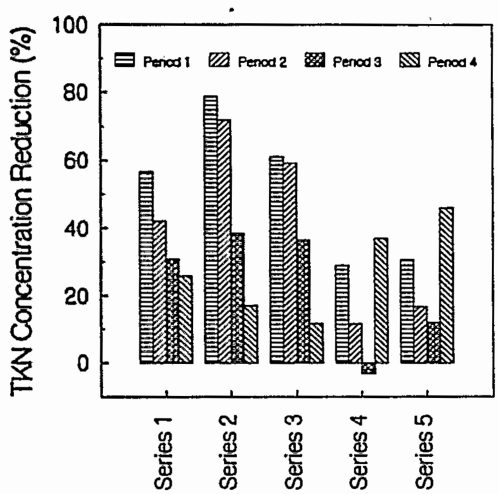


Figure 4. TKN removal in each series during the four periods.

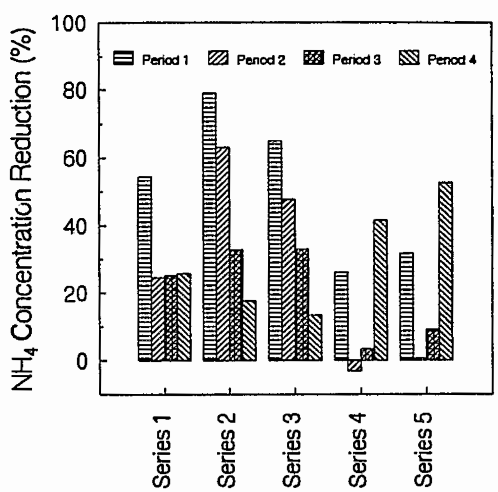


Figure 5. NH_4 removal in each series during the four periods.

Constructed Wetlands for Animal Waste Treatment

Appendix A Questionnaires for the Case Histories

CONSTRUCTED WETLANDS
FOR TREATING ANIMAL WASTES
QUESTIONNAIRE

1. Information on person(s) completing this questionnaire or or cooperating researchers:

   a. Name: Dr. Frank J. Humenik
   Address: N.C. State University
   Bio. & Ag. Eng., Box 7625
   Raleigh, NC 27695-7625
   Phone: 919/515-6767 Fax: 919/515-6772

   Your involvement/experience with this wetland system:

   ____
   ____

   b. Name: Dr. Patrick G. Hunt
   Address: USDA-ARS
   2611 West Lucas Street
   Florence, SC 29501-1241
   Phone: 803/669-5203 Fax: 803/669-6970

   Your involvement/experience with this wetland system:

   ____
   ____

   Others included on separate sheet: 1c. ☒ 1d. ☒

2. Location of the system (description or address):
   Duplin County, North Carolina
   ____

   Location in terms of latitude and longitude: Lat: 35° 02'
   Long: 77° 57'

3. Approximate percentage of funding for this project was provided by:

   EPA 74.2% State Water Quality Agency ____% TVA ____%
   USDA 12.3% State Experiment Station 10.1%
   Other: Private sources: Murphy Family Farms 3%
   NC Pork Producers Assoc. 0.4%

1c. Name: Mark Rice
Address North Carolina State University
Bio. & Ag. Eng., Box 7625
Raleigh, NC 27695-7625
Phone: 919/515-6794 Fax: 919/515-6772

Your involvement/experience with this wetland system:

____

____

1d. Name: Dr.Maurice Cook
Address North Carolina State University
Soil Science Dept., Box 7619
Raleigh, NC 27695-7619
Phone: 919/515-7303 Fax: 919/515-2167

Your involvement/experience with this wetland system:

____

____

1e. Name: Dr.Stephen Broome
Address North Carolina State University
Soil Science Dept., Box 7619
Raleigh, NC 27695-7619
Phone: 919/515-2643 Fax: 919/515-2167

Your involvement/experience with this wetland system:

____

____

1f. Name: Dr.Ariel Szogi
Address USDA-ARS
Coastal Plains Soil, Water & Plant Res. Ctr
2611 W. Lucas Street, Florence, SC 29501
Phone: 803/669-5203 Fax: 803/669-6970

Your involvement/experience with this wetland system:

____

____

1g. Name: George Stem
Address: USDA-Natural Resource Conservation Service, 4405 Bland Road, Suite 205
Raleigh, NC 27609
Phone: 919/873-2102 Fax: 919/873-2156

Your involvement/experience with this wetland system:

____

____

1h. Name: Mike Sugg
Address USDA-Natural Resource Conservation Service, Kenansville Field Office, PO Box 277
Kenansville, NC 28349
Phone: 910/296-2120 Fax: 910/296-2122

Your involvement/experience with this wetland system:

____

____

1i. Name: Gary Scalf
Address Murphy Family Farms
P. O. Box 759
Rose Hill, NC 28458
Phone: 910/289-2111 Fax: __________

Your involvement/experience with this wetland system:

____

____

4. Animal information:

Type: swine	Number: 2600	Avg. Wgt. 25
Type: ______	Number: ______	Avg. Wgt. ______
Type: ______	Number: ______	Avg. Wgt. ______
Type: ______	Number: ______	Avg. Wgt. ______
Type: ______	Number: ______	Avg. Wgt. ______

5. Date wetland system was installed: yr. 1992 month August
6. Date system became operational (first waste discharge): yr 1993 month June
7. Type of pretreatment (check one or describe):
   One cell lagoon X___ Two lagoon cells ___
   Waste Storage Pond (as defined by SCS or NRCS): ____
   Settling Basin ____
   Other: ______

8. Approximate age of pre-treatment units when wetland became operational: 2 yrs.

9. Had sludge ever been removed from the pre-treatment unit prior to installation of the wetland system? yes ___; ___yrs prior to installing wetland. No x

10. Basis for design of wetland system (i.e., 90 lbs. BOD/ac/day; minimum 7 day detention time; etc.) If a wetland/pond/wetland system was used, include design basis for pond and for entire system:

    Nitrogen loading of 3 kg/ha/day

11. Whose design criteria did you use? (TVA, SCS, private industry, etc.) List any references:
    SCS, National Bulletin No. 210-1-17

12. Total surface area (water surface) of wetland cells:
    720 m^2 or _____acres

13. Total surface area of pond cells: na m^2 or na acres

14. Surface area of the entire system including embankments
    3,200 m^2 or ____acres

15. Average water depth: 7.6 cm

16. Average slope of cells from upstream to downstream: 0.2 %

17. Provide a sketch in plan view showing the cells, embankments, and general location in relation to pretreatment units and other significant features. Provide dimensions for the cells and embankments. If preferred, attach engineering drawings from a publication and note here.

SEE ATTACHED FIGURE

18. Was the waste flow diluted prior to being discharged into the wetland system? No ____ Yes __x___
Source of dilution water was: ___Well___________________

Was dilution ratio changed during the course of the study?
Yes __x___, dilution ratio became ____% fresh water and ___% wastewater
Data in table, Items 25 and 26 is for initial dilution______
average of 10:1 and 6:1 dilution ratios
final dilution_________
(The initial dilution ratio was 10:1 in 1993. It was changed to approximately 6:1 in 1994 and in February 1996 was changed to 2:1.

19. Avg. Daily warm season flows (non-storm flows):
System 1: Influent 2900 liters/day
System 1: Effluent 2230 liters/day

System 2: Influent 3400 liters/day
System 2: Effluent 2050 liters/day

20. Avg. daily cool season flows (non-storm):
System 1: Influent 2700 liters/day
System 1: Effluent 1720 liters/day

System 2: Influent 3250 liters/day
System 2: Effluent 2360 liters/day

21. Describe flow controls at influent end of system (i.e., valves, swivel pipe, pump on timer, etc.)
valves

22. Any problems with clogging of influent pipes/valves with debris, struvite, animals, etc.?
There has been some clogging of the inlet valves.

Methods of control, if applicable:
Valves are flushed on a regular basis to inhibit buildup

23. Describe water level controls in the cells (i.e., downstream swivel pipe): Adjustable elbows between series cells, adjustable weir at the effluent end.

24. Any clogging of pipes between cells or from final outlet cells? No

Methods of control, if applicable:

25. Provide <u>average</u> concentrations in mg/L (or other appropriate units) for influent into the system and effluent from the system for warm (April-October) and cold (November-March)

Average for system 1

Parameter W = warm season C = cold season	Average Concentration or Reading		
	Influent	Effluent	Percent Change
BOD5(W)			
BOD5(C)			
COD(W)	75	64	14.7
COD(C)	115	71	38.3
NH_3+NH_4-N(W)	33	2	93.9
NH_3+NH_4-N(C)	65.5	8	87.8
Org-N(W) TKN	41	3	92.7
Org-N(C) TKN	78.5	10.5	86.6
Total P (W)	10	5	50
Total P (C)	11.5	9.5	17.4
PO_4-P (W)	7.5	2.6	65.3
PO_4-P (C)	13.5	8.5	37
TSS (W)			
TSS (C)			
D.O. (W)	N/A	N/A	N/A
D.O. (C)	N/A	N/A	N/A
Fecal coliforms (W) (No/100 ml)			
Fecal coliforms (C) No/100 ml)			
Fecal strep. (W)	N/A	N/A	N/A
Fecal strep. (C)	N/A	N/A	N/A
pH (W) (standard units)	8	7.7	3.7
pH (C)	8	7.6	5
Water temp. (W) (deg. C)	N/A	N/A	N/A
Water temp. (C)	N/A	N/A	N/A

26. Provide same information for <u>only the upstream cell(s).</u> If a bank of cells is used, provide average data for that bank of upstream cells.

Upstream cell(s) System 1

Parameter W = warm season C = cold season	Average Concentration or Reading		
	Influent	Effluent	Percent Change
BOD5(W)			
BOD5(C)			
COD(W)	75	38	49.3
COD(C)	114.5	52	54.6
NH_3+NH_4-N(W)	33	8.5	74.2
NH_3+NH_4-N(C)			
Org-N(W) TKN	N/A	N/A	N/A
Org-N(C) TKN	N/A	N/A	N/A
Total P (W)			
Total P (C)			
PO_4-P (W)	7.5	5	33.3
PO_4-P (C)	13.5	10.5	22.2
TSS (W)			
TSS (C)			
D.O.(W)	N/A	N/A	N/A
D.O.(C)	N/A	N/A	N/A
Fecal coliforms (W) (No/100 ml)			
Fecal coliforms (C) No/100 ml)			
Fecal strep. (W)	N/A	N/A	N/A
Fecal strep. (C)	N/A	N/A	N/A
pH (W) (standard units)	8	7.7	3.75
pH (C)	8	7.7	3.75
Water temp. (W) (deg. C)	N/A	N/A	N/A
Water temp. (C)	N/A	N/A	N/A

27. For the data in the above tables, what was the period of observation?

mo. 5 yr. 93 to mo. 10 yr. 94

25. Provide average concentrations in mg/L (or other appropriate units) for influent into the system and effluent from the system for warm (April-October) and cold (November-March)

Average for system 2

Parameter W = warm season C = cold season	Average Concentration or Reading		
	Influent	Effluent	Percent Change
BOD5(W)			
BOD5(C)			
COD(W)	75	64	14.7
COD(C)	75	81	8% increase
NH_3+NH_4-N(W)	33	1	96.9
NH_3+NH_4-N(C)	65.5	6.5	90.1
Org-N(W) TKN	41	3.5	96.9
Org-N(C) TKN	78.5	9.5	87.9
Total P (W)	10	4	60
Total P (C)	11.5	10	13
PO_4-P (W)	7.5	1.1	85.3
PO_4-P (C)	13.5	7	48.1
TSS (W)			
TSS (C)			
D.O.(W)	N/A	N/A	N/A
D.O.(C)	N/A	N/A	N/A
Fecal coliforms (W) (No/100 ml)			
Fecal coliforms (C) No/100 ml)			
Fecal strep. (W)	N/A	N/A	N/A
Fecal strep. (C)	N/A	N/A	N/A
pH (W) (standard units)	8	7.6	5
pH (C)	8	7.6	5
Water temp. (W) (deg. C)	N/A	N/A	N/A
Water temp. (C)	N/A	N/A	N/A

26. Provide same information for <u>only the upstream cell(s)</u>. If a bank of cells is used, provide average data for that bank of upstream cells.

Upstream cell(s) System 2

Parameter W = warm season C = cold season	Average Concentration or Reading		
	Influent	Effluent	Percent Change
BOD5(W)			
BOD5(C)			
COD(W)	75	35	53.3
COD(C)	114.5	50.5	55.9
NH_3+NH_4-N(W)	33	4	87.9
NH_3+NH_4-N(C)			
Org-N(W) TKN	N/A	N/A	N/A
Org-N(C) TKN	N/A	N/A	N/A
Total P (W)			
Total P (C)			
PO_4-P (W)	7.5	2	73.3
PO_4-P (C)	13.5	9	33.3
TSS (W)			
TSS (C)			
D.O.(W)	N/A	N/A	N/A
D.O.(C)	N/A	N/A	N/A
Fecal coliforms (W) (No/100 ml)			
Fecal coliforms (C) No/100 ml)			
Fecal strep. (W)	N/A	N/A	N/A
Fecal strep. (C)	N/A	N/A	N/A
pH (W) (standard units)	8	7.8	2.5
pH (C)	8	7.8	2.5
Water temp. (W) (deg. C)	N/A	N/A	N/A
Water temp. (C)	N/A	N/A	N/A

27. For the data in the above tables, what was the period of observation?

mo. <u>5</u> yr. <u>93</u> to mo. <u>10</u> yr. <u>94</u>

28. How many sampling days were included in the study? ____ days
May 27, 1993 to March 31, 1995 (245 observations)
February 4, 1994 to March 31, 1995 (51 observations)

29. What were maximum and minimum influent concentrations for:

a. Ammonia (NH_3 + NH_4-N): Max. 119 mg/l Min. 0.7 mg/l

b. Total suspended solids: Max. N/A mg/l Min. N/A mg/l

c. *Total phosphorus (TP): Max. 22 mg/l Min. 1.7 mg/l

d. Phosphate (PO_4-P): Max. 31 mg/l Min. 0.8 mg/l

***February 4,1994 to March 31, 1995 (51 observations)**

30. Which of the following represented a problem at your site (Elaborate as needed or place N/A if not applicable):

a. Insects destroyed particular plant species:
N/A

b. Muskrats or other animals created problems:
N/A

c. Plants were killed at upper end of cells because concentrations of ammonia or suspended solids were too high:
N/A

d. Evaporation rates were so high in summer that plants at lower end of system were killed or stressed:
The hydraulic flow rate is increased during the summer to maintain flow through the system.

e. Discharge limits could not be met for certain constituents in the final effluent:
List: The discharge limits for phosphorus could not be met at anytime, and the nitrogen limits only at low loading rates during warm seasons.

f. Phosphorus concentrations in the final effluent tended to increase over time:

g. Water management is a major problem. A water balance should be developed for any new systems which include:
✓(1) drawing down lagoon levels in late fall to accommodate winter storage of flush water and waste, rainwater on the lagoon surface, and runoff water;
✓(2) controlling water released to wetland system based on seasonal changes;
✓(3) collecting water discharged from the system and recycling or land applying;
✓(4) accounting for rainwater on the surface of the wetlands

(comments on need for water balance)

h. Mosquitoes were a problem: A two-year study was conducted by Mike Stringham in the Entomology Department at NCSU and found no significant population increase due to the wetlands

I. Uneven distribution of wastewater across all cells in a multi-cell system:

j. Others:

More thoughts on problems included on separate sheet ☐

31. What place do constructed wetlands have in managing animal wastes? What are the drawbacks? Should they be permitted for discharge?

The wetland should be a component in an overall waste management system. Based on our experience the wetlands are not able to consistently meet discharge requirements even at low nitrogen loading rates.

32. What additional research is needed on these systems?

The exact role and function of the wetlands and their most effective sequence in a waste treatment system need to be determined.

CONSTRUCTED WETLANDS
FOR TREATING ANIMAL WASTES
QUESTIONNAIRE

1. Information on person(s) completing this questionnaire or cooperating researchers:

   a. Name: Thomas A. McCaskey

   Address: Dept. of Animal and Dairy Sciences
   Auburn University
   Auburn University, AL 36849

   Phone: 334-844-1518 FAX: 334-844-1519

   Your involvement / experience with this wetland system:

   Principle Investigator

   ____

   b. Name: ______________________________

   Address: ______________________________

   ____

   ____

   Phone: ______________ FAX: ______________

   Your involvement / experience with this wetland system:

   ____

   ____

   Others included on separate sheet: 1c.□ 1d. □

2. Location of the system (description or address): Sand Mountain Agricultural Experiment Station, Crossville, AL

   Location in terms of latitude and longitude: Lat.__________ Long. __________

3. Approximate percentage of funding for this project was provided by:

   EPA 3 % State Water Quality Agency ___% TVA 20 % USDA 3 %

   State Experiment Station 74 % Other ______________________________

4. Animal information:

Type: Swine ______ Number: 500/yr ______ Avg. Wgt. 150 lb

Type: ______ Number: ______ Avg. Wgt. ______

Type: ______ Number: ______ Avg. Wgt. ______

Type: ______ Number: ______ Avg. Wgt. ______

Type: ______ Number: ______ Avg. Wgt. ______

5. Date wetland system was installed: yr. 1988 month fall
6. Date system became operational (first waste discharge): yr 1990 month Nov
7. Type of pre-treatment (check one or describe):

One cell lagoon____ Two lagoon cells x

Waste Storage Pond (as defined by SCS or NRCS):____

Settling Basin ___

Other:______________________________

8. Approximate age of pre-treatment units when wetland became operational: 12 yrs

9. Had sludge ever been removed from the pre-treatment unit prior to installation of the wetland system? yes x ; ___ yrs prior to installing wetland. no x

10. Basis for design of wetland system (i.e., 90 lbs BOD/ac/day; minimum 7 day detention time; etc.) If a wetland / pond / wetland system was used, include design basis for pond and for entire system: 65 lbs BOD/ac/day. See attache diagram

____

11. Whose design criteria did you use? (TVA, SCS, private industry, etc.) List any references:

TVA -- Don Hammer

12. Total surface area (water surface) of wetland cells:_____ m^2 or 1 acres

13. Total surface area of pond cells: _____ m^2 or 0.5 acres

14. Surface area of the entire system including embankments:_____ m^2 or 1.6 acres

15. Average water depth: 15.24 cm

16. Average slope of cells from upstream to downstream: < 1 %

17. Provide a sketch in plan view showing all cells, embankments, and general location in relation to pretreatment units and other significant features. Provide dimensions for the cells and embankments. If preferred, attach engineering drawings or drawings from a publication and note here.

See attached sketch

18. Was the waste flow diluted prior to being discharged into the wetland system? No____
Yes _x_ , dilution ratio was 30 % fresh water and 70 % wastewater
Source of dilution water was: gravity flow from a farm pond

Was dilution ratio changed during the course of the study? No
Yes__, dilution ratio became __% fresh water and ___% wastewater
Data in table, Items 25 and 26 is for initial dilution___ final dilution___

19. Avg. daily warm season flows (~~non-storm flows~~): NOTE: for all weather events
Influent 21,248 liters/day Effluent 14,146 liters/day

20. Avg. daily cool season flows (~~non-storm~~): NOTE: for all weather events
Influent 30,990 liters/day Effluent 48,770 liters/day

21. Describe flow controls at influent end of system(i.e., valves, swivel pipe, pump on timer, etc.)
Swivel pipe with flows checked daily

22. Any problems with clogging of influent pipes/ valves with debris, struvite, animals, etc.?
Only occassionally

Methods of control, if applicable:
Hand

23. Describe water level controls in the cells (i.e.,downstream swivel pipe):
Downstream swivel pipe

24. Any clogging of pipes between cells or from final outlet cells? No
However, a rock filter, containing a buried pipe to collect and distribute effluent to the next cell or storage pond, and the surface of this filter would need occassional cleaning
Methods of control, if applicable: Rake and hand cleaning

25. Provide average concentrations in mg/L (or other appropriate units) for influent into the system and effluent from the system for warm (April - October) and cold (November - March) seasons.

Average for the system*

Parameter W=warm season C=cold season	Average Concentration or Reading		
	Influent	Effluent	Percent Change
BOD5 ~~(W)~~ *All seasons*	76.6	7.7	87.1
~~BOD5 (C)~~			
COD ~~(W)~~	319.9	64.2	79.6
~~COD (C)~~			
NH_3+NH_4-N ~~(W)~~	55.6	8.6	84.5
~~NH_3+NH_4-N (C)~~			
Org-N ~~(W)~~	73.7	12.2	83.4
~~Org-N (C)~~			
Total P ~~(W)~~	28.4	6.8	46.1
~~Total P (C)~~			
PO_4-P ~~(W)~~	N/A		
~~PO_4-P (C)~~			
TSS ~~(W)~~	135.7	15.5	88.6
~~TSS (C)~~			
D.O. (W)	N/A		
D.O. (C)			
Fecal coliforms ~~(W)~~ (No./100 ml)	1.2×10^5	6.5×10^3	94.6
~~Fecal coliforms. (C)~~ (No./100 ml)			
Fecal strep. ~~(W)~~	4.7×10^4	1.9×10^3	96.0
~~Fecal strep. (C)~~			
pH ~~(W)~~ (standard units)	8.5	6.9	
~~pH (C)~~			
~~Water temp. (W)~~ deg C.	14.9		
~~Water temp. (C)~~			

* Data was not provided for warm and cool seasons; table is *all seasons* average for the system.

26. Provide same information for <u>only the upstream cell(s)</u>. If a bank of cells is used, provide average data for that bank of upstream cells.

Upstream cell(s) ***data provided only for average and not by season***

Parameter W=warm season C=cold season	Average Concentration or Reading		
	Influent	Effluent	Percent Change
BOD5 (~~W~~) *all seasons*	76.6	16.8	78.1
~~BOD5(C)~~			
COD (~~W~~) "	319.9	107.7	66.3
~~COD(C)~~			
NH_3+NH_4-N (~~W~~) "	55.6	20.7	62.8
~~NH_3+NH_4-N (C)~~			
Org-N (~~W~~) "	18.1	6.4	64.6
~~Org-N (C)~~			
Total P (~~W~~) "	28.4	12.7	55.3
~~Total P (C)~~			
PO_4-P (~~W~~)	N/A		
~~PO_4-P (C)~~			
TSS (~~W~~)	135.7	19.1	85.9
~~TSS (C)~~			
D.O. (W)	N/A		
D.O. (C)			
Fecal coliforms (~~W~~) (No./100 ml)			
~~Fecal coliforms. (C)~~ (No./100 ml)			
Fecal strep. (~~W~~)			
~~Fecal strep. (C)~~			
pH (~~W~~) (standard units)			
~~pH (C)~~			
Water temp. (~~W~~) (deg. C)	Air temp only; see previous sheet.		
~~Water temp. (C)~~			

27. For the data in the above tables, what was the period of observation?

mo. <u>11</u> yr. <u>90</u> to mo. <u>5</u> yr. <u>95</u>

28. How many sampling days were included in the study? ___ days

29. What were maximum and minimum influent concentrations for:

a. Ammonia ($NH_3 + NH_4$-N): Max. ________ mg/L Min. ___mg/L
b. Total suspended solids: Max ________ mg/L Min. _______mg/L
c. Total phosphorus (TP): Max ________ mg/L Min ____mg/L
d. Phosphate (PO_4-P): Max ________mg/L Min _______mg/L

30. Which of the following represented a problem at your site (Elaborate as needed or place N/A if not applicable):

a. Insects destroyed particular plant species:
Yes. Cattapillars invaded cattail cells at different times.

b. Muskrats or other animals created problems:
Yes. Muskrats burrowed into embankments. One cell was drained though an outside embankment. Control of muskrats was essential.

c. Plants were killed at upper end of cells because concentrations of ammonia or suspended solids were too high:
No

d. Evaporation rates were so high in summer that plants at lower end of system were killed or stressed:
No

e. Discharge limits could not be met for certain constituents in the final effluent:
List: If a discharge were allowed, limits could not be met at some time for many constituents.

f. Phosphorus concentrations in the final effluent tended to increase over time:

g. Water management is a major problem. A water balance should be developed for any new systems which include:
(1) drawing down lagoon levels in late fall to accommodate winter storage of flush water and waste, rainwater on the lagoon surface, and runoff water;
(2) controlling water released to wetland system based on seasonal changes;
(3) collecting water discharged from the system and recycling or land applying;
(4) accounting for rainwater on the surface of the wetlands.

(comments on need for water balance)

h. Mosquitoes were a problem: ______No______________________________

i. Uneven distribution of wastewater across all cells in a multi-cell system: ____No___
____

j. Others: ____
____
____

More thoughts on problems included on separate sheet □

31. What place do constructed wetlands have in managing animal wastes? What are the drawbacks? Should they be permitted for discharge?

32. What additional research is needed on these systems?

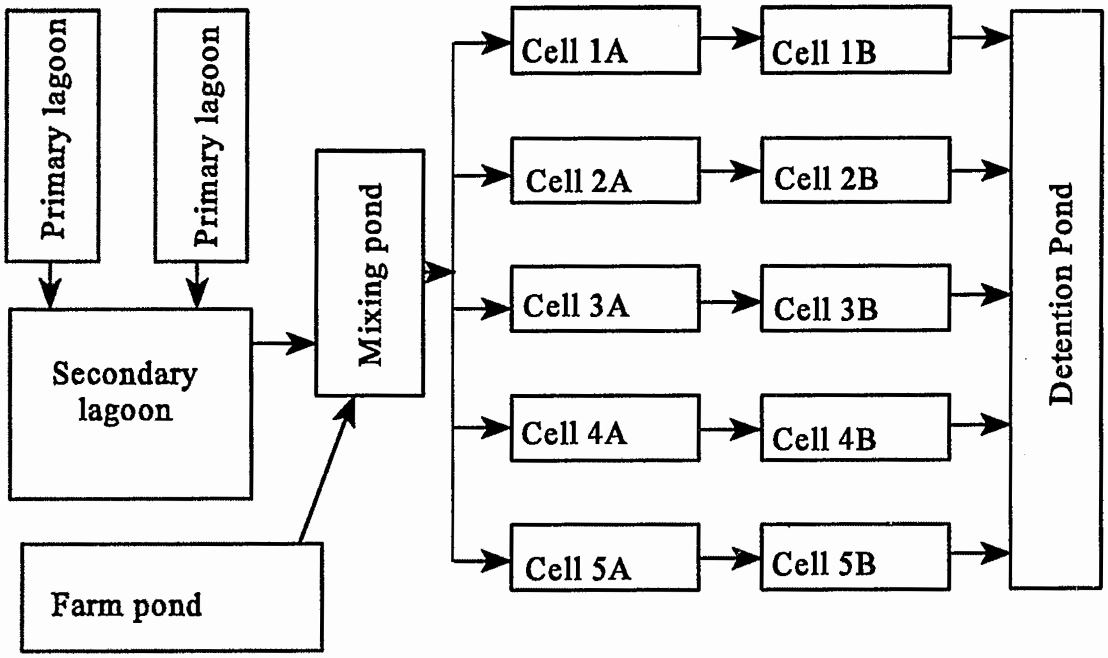


Figure 1. Generalized flow diagram of the Sand Mountain Constructed Wetland System at the Agricultural Experiment Station, Crossville, AL

CONSTRUCTED WETLANDS
FOR TREATING ANIMAL WASTES
QUESTIONNAIRE

1. Information on person(s) completing this questionnaire or cooperating researchers:

a. Richard Reaves
Biologist
3D/International, Environmental Group
781 Neeb Road
Cincinnati, OH 45233-4625
phone: 513-922-8199 fax: 513-922-9150
email: rreaves@cinternet.net

Involvement/experience with the project:
Water quality monitoring, data analysis, reporting to regulatory agencies, outreach activities

b. Brain Miller
Coordinator, Marine Advisory Services
Illinois-Indiana Sea Grant Program
1159 Forestry Building
Purdue University
West Lafayette, IN 47907-1159
phone: 317-494-3586 fax: 317-496-2422
email: brian_miller@acn.purdue.edu

Involvement/experience with the project:
Reporting to regulatory agencies, outreach activities

c. Paul DuBowy
Associate Professor
Dept. of Wildlife & Fisheries Sciences
Texas A&M University
210 Nagle Hall
College Station, TX 77843-2258
phone: 409-845-5765 fax: 409-845-3786
email: p-dubowy@tamu.edu

Involvement/experience with the project:
Reporting to regulatory agencies, outreach activities, landowner-agency coordination

2. Location of the system:

Tom Brothers' Dairy
5377 East 800 North
Syracuse, IN 46567

Location in terms of latitude and longitude:

Lat.: 41° 20' 30" Long.: 85° 46' 30"

3. Approximate percentage of funding for this project was provided by:

EPA 319 funds administered by the Indiana Department of Environmental Management funded approximately 90% of this project; Purdue University provided the remaining 10% of the funding.

4. Animal Information:

Type: dairy Number: 80 Avg.Wgt.: 630 kg

5. Date Wetland system installed:

yr. 1994 month: November

6. Date system became operational (first waste discharge):

yr.: 1995 month: May

7. Type of pretreatment:

A stack pad for drying manure coupled with a septic pit for solids removal from liquid waste.

8. Approximate age of pretreatment units when system became operational:

10 yr.

9. Had sludge ever been removed from the pre-treatment unit prior to installation of the wetland system?

Yes; 1 year prior to wetland installation.

10. Basis for design of wetland system:

The presumptive method for sizing wetland basin based on 65 pounds of BOD per acre per day, modified by designing wetland basin to accommodate 25-year, 24-hour storm event.

11. Whose design criteria did you use?

SCS guidelines were used, the design was done by Indiana SCS State Engineer.

12. Total surface area (water surface) of wetland cells:

Cell 1 approximately 900 m^2
Cell 2 approximately 950 m^2

13. Total surface area of pond cells:

approximately 1200 m^2

14. Surface area of entire system including embankments:

approximately 4000 m^2

15. Average water depth:

inflow to cell: 4 cm cell outflow: 20 cm

16. Average slope of cells from upstream to downstream:

0.25%

17. Provide a sketch in plan view showing all cells, embankments, and general location in relation to pretreatment units and other significant features. Provide dimensions for the cells and embankments. If preferred, attach engineering drawings from a publication and note here.

Drawings are attached: a general schematic and various engineering drawings.

18. Was the waste flow diluted prior to being discharged into the wetland system?

No, but surface runoff from surrounding uplands (pasture and no-till row crop) was diverted and directed into the first cell approximately 60% of the way from the inlet to the outlet. Most times this water was cleaner than wastewater in the cell and provided a dilution at the point of entry. Occasionally, the runoff contained higher concentrations of various contaminants and the entry point provided a form of step loading for the first cell.

19. Average daily warm season inflows (non-storm flows):

Influent: 750 L/d, milkhouse washwater and waste runoff.

Effluent: not measured, most of the growing season, there was no outflow resulting from high evapotranspiration rates.

20. Average daily cool season inflows (non-storm flows):

Influent: 750 L/d, milkhouse washwater and waste runoff.

Effluent: not measured.

21. Describe flow controls at influent end of system:

Gravity flow by overflow from the septic pit into system piping. Switching valves allow direction of waste flow into either of the wetland cells or sequentially through both cells. This allows continued operation if one cell is out of service. Horizontal slotted PVC pipe provided inflow distribution across the width of the cells.

22. Any problems with clogging of influent pipes/valves with debris, struvite, animals, etc.?

Occasional blockage of slotted PVC pipe with debris.

Methods of control, if applicable:

manual removal of debris

23. Describe water level controls in the cells:

Bottom fed risers with adjustable 4-inch plastic depth regulators in each cell. Surface overflow from holding pond into infiltration area

24. Any clogging of pipes between cells or from final outlet cells?

Occasional blockage of slotted PVC pipe that redistributed flow across the head of cell 2 with debris (primarily tree leaves in fall). No problems with blockage of outflow riser structures of pipes between cells.

Methods of control, if applicable:

manual removal of debris

25. Provide average concentrations in mg/L or other appropriate units for entire system warm season (May-October) and cold season (November-April) influent and effluent:

I redefined warm and cold season for this system. Warm season does not start at this system until May.

There are two things worth noting when examining these numbers.

1. There was a substantial difference in the quality of wastewater entering the system between the two years. The total averages for the two years are probably lower than would be expected for long-term operation because wetland influent quality during the first year was exceptionally good. Influent quality during the second year was probably typical for a dairy of this size.
2. Effluent values are given for the outflow of the second cell. The system has a holding pond downstream of the second cell that can provide additional treatment after effluent leaves the second cell. However, because the open pond attracts wildlife and provides an exceptionally good environment for algal growth, it also can result in decreases in water quality after leaving the second cell.

Parameter W = warm season C = cold season	Average Concentration or Reading		
	Influent	Effluent	Percent change
BOD5 (W)	372.08	22.84	-93.9%
BOD5 (C)	696.83	63.89	-90.8%
COD (W)	not measured	not measured	not determined
COD (C)	not measured	not measured	not determined
(NH3+NH4)-N (W)	74.36	11.58	-81.4%
(NH3+NH4)-N (C)	192.18	9.08	-95.3%
Org-N (W)	13.25	6.81	-48.6%
Org-N (C)	25.32	6.46	-74.5%
Total-P (W)	13.31	3.15	-76.33%
Total-P (C)	19.16	1.83	-90.4%
PO4-P (W)	8.94	2.60	-70.9%
PO4-P (C)	8.32	1.35	-83.8%
TSS (W)	81	83	+2.5%
TSS (C)	74	17	-77.0%
DO (W)	0.99	5.05	+410.1%
DO (C)	2.70	6.86	+154.1%
Fecal coliforms (W) colonies per 100 mL	96	4	-95.8%
Fecal coliforms (C) colonies per 100 mL	222	8	-96.4%
Fecal Strep. (W)	not measured	not measured	not determined
Fecal Strep. (C)	not measured	not measured	not determined
pH (W)	7.58	7.74	+2.1%
pH (C)	7.26	7.44	+2.5%
Water temp. (W)	20.71	21.73	+4.9%
Water temp. (C)	6.67	10.75	+61.2%

25. Provide average concentrations in mg/L or other appropriate units for upstream cell only warm season (May-October) and cold season (November-April) influent and effluent: (Warm season does not start at this system until May.)

Parameter W = warm season C = cold season	Average Concentration or Reading		
	Influent	Effluent	Percent change
BOD5 (W)	372.08	68.28	-81.6%
BOD5 (C)	696.23	174.24	-75.0%
COD (W)	not measured	not measured	not determined
COD (C)	not measured	not measured	not determined
(NH3+NH4)-N (W)	74.36	50.47	-32.1%
(NH3+NH4)-N (C)	192.18	87.93	-54.2%
Org-N (W)	13.25	8.79	-33.7%
Org-N (C)	25.32	9.65	-61.9%
Total-P (W)	13.31	8.58	-35.5%
Total-P (C)	19.16	5.56	-71.0%
PO4-P (W)	8.94	7.66	-14.3%
PO4-P (C)	8.32	4.52	-45.7%
TSS (W)	81	71	-12.3%
TSS (C)	74	43	-41.9%
DO (W)	0.99	1.84	+85.9%
DO (C)	2.70	3.56	+31.9%
Fecal coliforms (W) colonies per 100 mL	96	14	-85.4%
Fecal coliforms (C) colonies per 100 mL	222	43	-80.6%
Fecal Strep. (W)	not measured	not measured	not determined
Fecal Strep. (C)	not measured	not measured	not determined
pH (W)	7.58	7.66	+1.1%
pH (C)	7.26	7.37	+1.5%
Water temp. (W)	20.71	20.04	-3.2%
Water temp. (C)	6.67	6.94	+4.0%

27. For the data in the above tables, what is the period of observation?
for most parameters: May, 1994 to October, 1995

for pH, DO, and temperature July, 1994 to October, 1995

28. How many sampling days were included in the study?
33 sampling dates for most parameters
29 sampling dates for pH, DO, and water temperature

29. What were maximum and minimum influent concentrations for:

Parameter	Maximum (mg/L)	Minimum (mg/L)
Ammonia ((NH3+NH4)-N)	435.32	0.00
TSS	757	9
TP	36.44	0.59
PO4-P	29.01	0.00

30. Which of the following represented a problem at your site (elaborate as needed or place N/A if not applicable).

a) Insects destroyed a particular plant species: N/A

b) Muskrats or other animals created problems:

Deer trampled largest cattails, there was no observable adverse impact to the system.

c) Plants were killed at the upper end of cells because concentrations of ammonia or suspended solids were too high: N/A

d) Evapotranspiration rates were so high in summer that plants at lower end of system were killed or stressed:

Due to bottom slope of cells, plants at upper end of system were stressed from low water in summer.

e) Discharge limits could not be met for certain constituents in the final effluent:

This was a no discharge system so this aspect was not applicable.

f) Phosphorus concentrations in final effluent tended to increase over time:

Total-P concentrations were higher at the end of the 2-year period, but inflow levels were much higher at this time. Higher outflow rates probably resulted from increased loading rather than phosphorus saturation within the wetland system.

g) Water management is a major problem. A water balance should be developed for any new systems which include:

1) **drawing down lagoon levels in late fall to accommodate winter storage of flush water and waste, rainwater on the lagoon surface, and runoff water;**
2) **controlling water released to wetland system based on seasonal changes;**
3) **collecting water discharged from the system and recycling or land applying;**
4) **accounting for rainwater on the surface of wetlands.**

(comments on the need for water balance)

A) With gravity flow into a terminal infiltration area, item number three on the above list is less critical. However, design must include major storm events in infiltration area design for proper functioning.
B) Wetland design should include average expected rainfall as part of the flow volume to be treated. Water volume from major storm events should be handled separate from the wetland basins, either with storage ponds or lagoons.
C) Water level management is the most important task that producers must do once wetland systems are in place. Adjusting flows and volumes to allow vegetation establishment and to handle high flow volumes is critical. This is especially important in seasonal climates such as the upper midwest. The period of high flow from rainfall and snowmelt coincides with early spring when temperatures are low and microbial activity is low. High volumes can move through wetland systems at a time when treatment efficiency is low. Proper design and water level management allows storage of excess liquids for release to the wetland during times when microbial activity and waste treatment are high.

h) Mosquitoes were a problem:

The landowners stated that they noticed no problems with mosquitoes during the two years of the study.

I) Uneven distribution of wastewater across all cells in a multi-cell system: N/A

31. What place do constructed wetlands have in managing animal wastes? What are the drawbacks? Should they be permitted for discharge?

1. Constructed wetlands can be successfully integrated into an onfarm total waste management system. Site conditions (topography, soils) are prime determinants of whether a particular operation will find wetland treatment systems an economically viable option for inclusion in waste management systems. The degree of treatment needed from a wetland system will vary depending upon the level of pretreatment and the needs of particular producers.

2. A particular drawback to widespread use of these systems is the extreme variation in regulations governing animal waste treatment systems. Regulations impose particular design and/or operation constraints on wetland systems. A system that works well in one state may be excluded from another state because of the regulatory climate.

3. The issue of discharge is rather complex. Discharge may not be desirable in all situations. A producer wishing to obtain nutrient benefits through land application of wastewater will not want to treat wastewater to the point of meeting discharge standards. on the other hand, some producers may need to eliminate excess water. In such a situation, discharge becomes a desirable goal. If one looks at individual onsite wetland systems, animal waste treatment wetlands that obtain NPDES discharge standards should be permitted for discharge into waterways, provided that NPDES monitoring is done to determine compliance. It seems reasonable to expect the same degree of monitoring as industry and municipalities face for discharge. This may not be an economically viable option for many animal production operations. Water quality monitoring and reporting are additional time and money expenses that a producer may not be able to afford. However, if a total watershed approach is adopted where onsite wetland systems discharge through other collective treatment wetlands, discharge without onsite monitoring may be practical. As with any unmonitored situation, the potential for bad actors exists. Without onsite monitoring, there is no way to guarantee wetland systems will be properly maintained.

32. What additional research is needed on these systems?

1. Further work is needed on integrating site-specific waste treatment systems into a full watershed-level NPS control program.

2. Additional work is needed to support life expectancy projections for animal waste treatment wetlands, examining effects of management practices, climate, and different solid loading rates.

3. Given the public perception of the risks associated with water-borne pathogens, investigations into the mechanisms of pathogen removal and design criteria that can enhance pathogen removal are probably warranted.

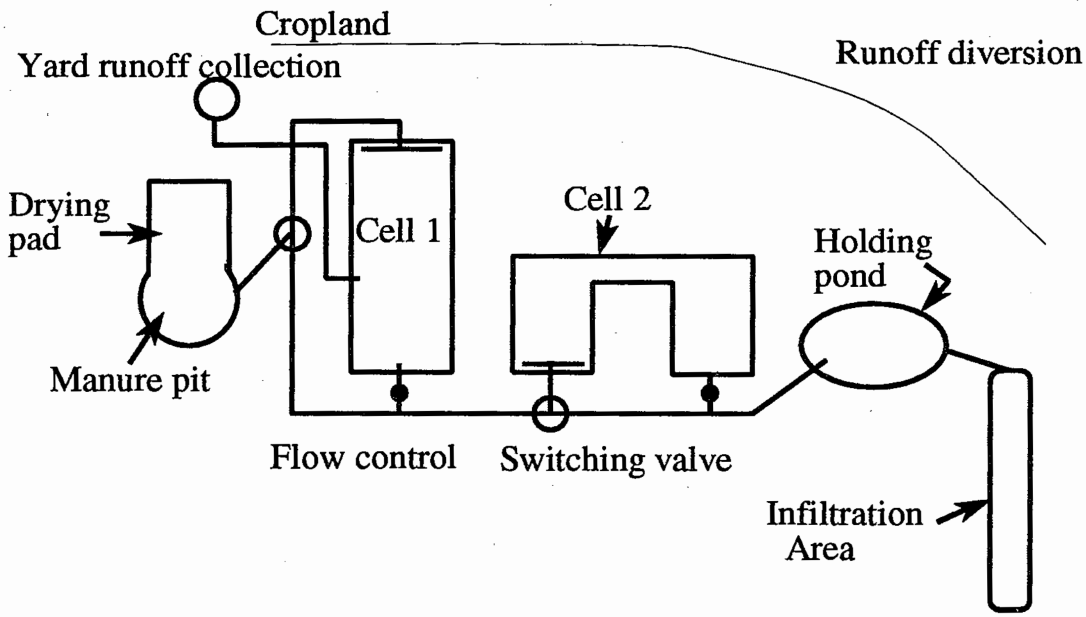


Figure 1. Generalized layout of waste treatment system at Tom Brothers' Dairy

CONSTRUCTED WETLANDS
FOR TREATING ANIMAL WASTES
QUESTIONNAIRE

1. Information on person(s) completing this questionnaire or cooperating researchers:

a. Name: Dr. Charles M. Cooper
Address: USDA-ARS
National Sedimentation Laboratory
P. O. Box 1157, Oxford, MS 38655

Phone: 601-232-2933 FAX: 601-232-2915
Your involvement / experience with this wetland system:

Supervised management and monitoring of wetland treatment system

b. Name: Samuel Testa III
Address: USDA-ARS
National Sedimentation Laboratory
P. O. Box 1157, Oxford, MS 38655
Phone: 601-232-2933 FAX: 601-232-2915
Your involvement / experience with this wetland system:

Water quality sampling and monitoring, and maintenance of wetland treatment system

Others included on separate sheet: 1c.□ 1d. □

2. Location of the system (description or address): Scott Dairy Farm, 5 miles ESE Hernando, MS

Location in terms of latitude and longitude: Lat. N34° 45' Long. W89° 54'

3. Approximate percentage of funding for this project was provided by:

EPA____% State Water Quality Agency ___% TVA ___% USDA 100 %

State Experiment Station ___% Other ________________

4. Animal information:

Type: Hostein dairy	Number: 60 - 100 range	Avg. Wgt. 1000-1200 lb
Type:_____	Number: _____	Avg. Wgt. _____
Type:_____	Number: _____	Avg. Wgt. _____
Type:_____	Number: _____	Avg. Wgt. _____
Type:_____	Number: _____	Avg. Wgt. _____

5. Date wetland system was installed: yr. 1990 month April
6. Date system became operational (first waste discharge): yr 1991 month April
7. Type of pre-treatment (check one or describe):
   One cell lagoon x   Two lagoon cells ____
   Waste Storage Pond (as defined by SCS or NRCS): _____
   Settling Basin ___
   Other:_____

8. Approximate age of pre-treatment units when wetland became operational: 1 yr

9. Had sludge ever been removed from the pre-treatment unit prior to installation of the wetland system? yes___ ; ___ yrs prior to installing wetland.   no x

10. Basis for design of wetland system (i.e., 90 lbs BOD/ac/day; minimum 7 day detention time; etc.) If a wetland / pond / wetland system was used, include design basis for pond and for entire system: See attached computation sheets

11. Whose design criteria did you use? (TVA, SCS, private industry, etc.) List any references:

USDA-SCS: Jimmy Wilson, District Engineer, New Albany, MS

12. Total surface area (water surface) of wetland cells: 432 m^2 or ______acres

13. Total surface area of pond cells: 0 m^2 or ______acres

14. Surface area of the entire system including embankments: ≅700 m^2 or _____acres

15. Average water depth: ≅ 25 cm

16. Average slope of cells from upstream to downstream: > 1 %

17. Provide a sketch in plan view showing all cells, embankments, and general location in relation to pretreatment units and other significant features. Provide dimensions for the cells and embankments. If preferred, attach engineering drawings or drawings from a publication and note here.

See attached plan

18. Was the waste flow diluted prior to being discharged into the wetland system? No_x_
Yes__, dilution ratio was __% fresh water and __% wastewater
Source of dilution water was:____

Was dilution ratio changed during the course of the study?
Yes__, dilution ratio became __% fresh water and ___% wastewater
Data in table, Items 25 and 26 is for initial dilution___ final dilution___

19. Avg. daily warm season flows (non-storm flows):
Influent _1354_ liters/day Effluent_576_ liters/day

20. Avg. daily cool season flows (non-storm):
Influent _1368_ liters/day Effluent _749_ liters/day

21. Describe flow controls at influent end of system(i.e., valves, swivel pipe, pump on timer, etc.)
4000 liter constant head tank led to inflow at cells where drilled hole in PVC pipe end cap gave desired volume/time. Different sized holes in threaded endcaps could be used to change flow rates

22. Any problems with clogging of influent pipes/ valves with debris, struvite, animals, etc.?
Original equipment gate valves for control (and ball valves) needed frequent remedial action. Drilled endcaps fed from head tank rarely required maintenance.

Methods of control, if applicable:
Lagoon discharge to wetland protected by ½ inch hardware cloth

23. Describe water level controls in the cells (i.e.,downstream swivel pipe):
Downstream swivel pipe

24. Any clogging of pipes between cells or from final outlet cells? None

Methods of control, if applicable: Outflow from cells first passed though a submerged perforated (½ inch holes) 3-in. PVC pipe (with endcaps) that spanned the lower end of the cell, plumbed at center to discharge pipe.

25. Provide average concentrations in mg/L (or other appropriate units) for influent into the system and effluent from the system for warm (April - October) and cold (November - March) seasons.

Average for the system

Parameter W=warm season C=cold season	Average Concentration or Reading		
	Influent	Effluent	Percent Change
BOD5 (W) mg/L	30.0	9.5	68.3
BOD5 (C) "	31.1	5.1	83.7
COD (W) "	244	122	50
COD (C) "	343	80	77
NH_3+NH_4-N (W) "	5.54	1.80	67.5
NH_3+NH_4-N (C) "	8.02	1.55	80.6
Org-N (W)			
Org-N (C)			
Total P (W) mg/L	12.66	7.19	43.2
Total P (C) "	20.83	7.67	63.2
PO_4-P* (W) "	8.59	4.96	42.2
PO_4-P* (C) "	11.20	6.40	42.9
TSS (W) "	128.1	53.4	58.3
TSS (C) "	110.8	33.0	70.2
D.O. (W) "	2.87	1.43	50.2
D.O. (C) "	4.77	2.58	45.8
Fecal coliforms (W) (No./100 ml)	9,969	1,136	88.6
Fecal coliforms. (C) (No./100 ml)	19,968	595	97.0
Fecal strep. (W)			
Fecal strep. (C)			
pH (W) (standard units)	6.86	6.15	10.8
pH (C)	7.20	6.52	9.4
Water temp. (W) deg C	22.5	20.4	9.1
Water temp. (C)	11.2	9.4	16.0

* Filterable ortho-P

26. Provide same information for <u>only the upstream cell(s)</u>. If a bank of cells is used, provide average data for that bank of upstream cells.

Upstream cell(s) ----- NOT TAKEN---

Parameter W=warm season C=cold season	Average Concentration or Reading		
	Influent	Effluent	Percent Change
BOD5 (W)		Same as wetland influent	
BOD5(C)			
COD (W)			
COD(C)			
NH_3+NH_4-N (W)			
NH_3+NH_4-N (C)			
Org-N (W)			
Org-N (C)			
Total P (W)			
Total P (C)			
PO_4-P (W)			
PO_4-P (C)			
TSS (W)			
TSS (C)			
D.O. (W)			
D.O. (C)			
Fecal coliforms (W) (No./100 ml)			
Fecal coliforms. (C) (No./100 ml)			
Fecal strep. (W)			
Fecal strep. (C)			
pH (W) (standard units)			
pH (C)			
Water temp. (W) (deg. C)			
Water temp. (C)			

27. For the data in the above tables, what was the period of observation?

mo. 5 yr. 91 to mo. 5 yr. 94

28. How many sampling days were included in the study? __181__ days

29. What were maximum and minimum influent concentrations for:

a. Ammonia ($NH_3 + NH_4$-N): Max. __30.8__ mg/L Min. __0.1__ mg/L
b. Total suspended solids: Max __466__ mg/L Min. __0__ mg/L
c. Total phosphorus (TP): Max __69__ mg/L Min __1.3__ mg/L
d. Phosphate (PO_4-P)*: Max __24__ mg/L Min __0.9__ mg/L
*Filterable ortho-P

30. Which of the following represented a problem at your site (Elaborate as needed or place N/A if not applicable):

a. Insects destroyed particular plant species:
Grasshoppers caused moderate damage during late summer of one year to *Scripus validus* in monoculture.

b. Muskrats or other animals created problems:
No

c. Plants were killed at upper end of cells because concentrations of ammonia or suspended solids were too high:
No plant death was seen, but noticeable yellowing and stunting ocurred immeidiately after first wastewater introduced.

d. Evaporation rates were so high in summer that plants at lower end of system were killed or stressed:
No, but water column became very shallow at times.

e. Discharge limits could not be met for certain constituents in the final effluent:
List: N/A

f. Phosphorus concentrations in the final effluent tended to increase over time:
Yes. See attached graph.

g. Water management is a major problem. A water balance should be developed for any new systems which include:
(1) drawing down lagoon levels in late fall to accommodate winter storage of flush water and waste, rainwater on the lagoon surface, and runoff water;
(2) controlling water released to wetland system based on seasonal changes;
(3) collecting water discharged from the system and recycling or land applying;
(4) accounting for rainwater on the surface of the wetlands.

(comments on need for water balance)
Design should allow for accomodating strom events.

h. Mosquitoes were a problem: Never

i. Uneven distribution of wastewater across all cells in a multi-cell system: No
None noticed

j. Others:

More thoughts on problems included on separate sheet ☐

31. What place do constructed wetlands have in managing animal wastes? What are the drawbacks? Should they be permitted for discharge?

See attached sheet

32. What additional research is needed on these systems?

See attached sheet

Question #31.

Constructed wetlands are useful as secondary treatment of animal wastes, but at present should probably only be used at the tertiary level for final polishing of wastewater. At present, generality of design is a drawback, as systems attempt to deal with a variety of pollutants and physical/environmental conditions. More site-specific design criteria are necessary for particular contaminants and specific conditions, which may also lead us to a better knowledge of the processes occurring in constructed wetlands. Current permitting should not be allowed for release into surface waters of the nation unless the systems are greatly overdesigned, and capable of handling the large variability inherent to these living systems.

Question #32.

Constructed wetland systems for waste treatment so far have mostly been general, catch-all systems. Design criteria need to be developed for particular pollutants and site characteristics, allowing better control and predictability. Recent research at our wetland system indicates that some nitrate-reducing bacteria also reduce iron. This may be important when iron is present at the site, there is potential for nitrate-reducing bacteria to be already present. Additional research is also needed concerning longevity of these systems. It has already been demonstrated that phosphorus trapping potential decreases sharply after relatively short times of operation, and we have information on the processes causing this effect. Processes controlling other pollutant dynamics are much less well understood. Long-term capabilities of these systems for treating other pollutants are also less well known, and procedures for re-attaining lost treatment capability need to be developed. Routine maintenance procedures may be developed which help sustain the treatment capability of constructed wetlands, but much more information is necessary concerning the physical and biological processes before these procedures can be ascertained.

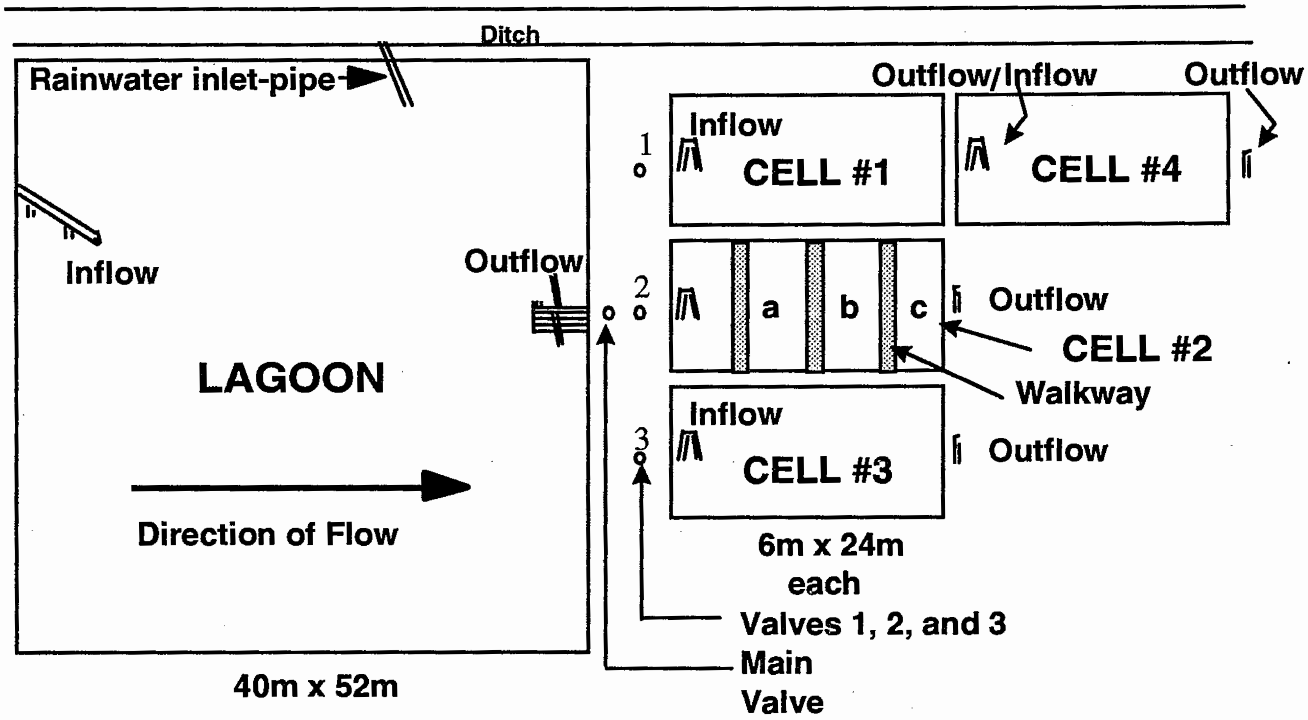


Figure 1. Layout of lagoon\wetland cell system at Hernando

Site Information Summary

Type project: Constructed wetland for treating dairy wastewater

Contact details:

Paul Hermans, P.Ag.
Essex Region Conservation Authority
360 Fairview Avenue, West
Essex, Ont., CN N8M 1Y6
Ph. (519) 776-5209
Fax #: (519) 776-8688

Site Name: Malden Valley Farms Constructed Wetland
Sytem Name: Constructed wetland for dairy operation wastes
Country: Canada
Province/State: Ontario
City/Community: Woodske
Description of Waste Production Facility:
200 head dairy; 65 milking cows; 200 gallons of milkhouse waste per day; manure lot runoff

Wastewater Pretreatment: Solids separation in barnyard
Stormwater: Watershed Area: 0.25 ha
% Impervious (Roofs, parking lots, etc.) 100%

Wetland Hydrologic Type (surface flow, subsurface flow, hybrid, etc)
surface flow wetland
Number of Cells: three: pond/marsh/pond
Cell configuration and dimensions: see attached drawing
Cell length: 120 m Cell width: 5 m
Cell bottom slope: 0.25% Cell avg depth: 0.30 m (avg. 0-0.6 m)
Substrate material: clay
Predominant plant species: cattail
Captial cost: $18,000
Climatic Data:
Avg # frost free days: 154 (May 4 - Oct 6)
Avg annual temp (°C) 8.9 Avg winter temp -3.4
Annual snowfall (cm) 100 Annual rainfall (cm): 712
Elevation (msl): 182 m

CONSTRUCTED WETLANDS
FOR TREATING ANIMAL WASTES
QUESTIONNAIRE

1. Information on person(s) completing this questionnaire or cooperating researchers:

   a. Name: James A. Moore
   Address: Department of Bioresource Engineering
   Oregon State University
   Corvallis, OR 97330
   Phone: 541/737-2041 FAX: 541/737-2082
   Your involvement / experience with this wetland system:

   Principal Investigator

   Email: moorej@ccmail.orst.edu

   b. Name: Steven F. Niswander
   Address: Dept. of Bioresource Engineering
   Oregon State University
   Corvallis, OR 97330
   Phone: 541/737-6296 FAX: 541/737-2082
   Your involvement / experience with this wetland system:

   Graduate Research Assistant

   Email: niswands@pandora.bre.orst.edu

   Others included on separate sheet: 1c. ☒ 1d. ☐

2. Location of the system (description or address): Oregon State University Campus Dairy

   Location in terms of latitude and longitude: Lat. 44°37' Long. 123°12'

3. Approximate percentage of funding for this project was provided by:

   EPA 20 % State Water Quality Agency ___% TVA ___% USDA 60 %

   State Experiment Station 15 % Other Oregon Dairy Farmers Association - 5%

4. Animal information:

Type: Milking	Number: 175	Avg. Wgt. 1,400 lbs
Type: ______	Number: ______	Avg. Wgt. ______
Type: ______	Number: ______	Avg. Wgt. ______
Type: ______	Number: ______	Avg. Wgt. ______
Type: ______	Number: ______	Avg. Wgt. ______

5. Date wetland system was installed: yr. 1992 month May
6. Date system became operational (first waste discharge): yr 1993 month October
7. Type of pre-treatment (check one or describe):

   One cell lagoon ___ Two lagoon cells ___

   Waste Storage Pond (as defined by SCS or NRCS): ___

   Settling Basin ___

   Other: Solids separator

8. Approximate age of pre-treatment units when wetland became operational: N/A

9. Had sludge ever been removed from the pre-treatment unit prior to installation of the wetland system? yes ___; ___yrs prior to installing wetland. no X

10. Basis for design of wetland system (i.e., 90 lbs BOD/ac/day; minimum 7 day detention time; etc.) If a wetland / pond / wetland system was used, include design basis for pond and for entire system: 100 mg NH_3/1; Total solids 1,500 mg/1

BOD 74 kg/ha-day

11. Whose design criteria did you use? (TVA, SCS, private industry, etc.) List any references:

USEAP 1988. Design manual on constructed wetlands and aquatic plant systems for municipal wastewater treatment. EPA/625/1-88/022.

12. Total surface area (water surface) of wetland cells: 784 m^2 or ______acres

13. Total surface area of pond cells: 98 m^2 or ______acres Deep water sections Pond 4 and 9

14. Surface area of the entire system including embankments: 2,500 m^2 or ______acres

15. Average water depth: 30 cm

16. Average slope of cells from upstream to downstream: 0.5 %

17. Provide a sketch in plan view showing all cells, embankments, and general location in relation to pretreatment units and other significant features. Provide dimensions for the cells and embankments. If preferred, attach engineering drawings or drawings from a publication and note here.

See figure 1-5. Note these are design drawings and acutal size of ponds is slightly different.

18. Was the waste flow diluted prior to being discharged into the wetland system? No __
Yes_x, dilution ratio was 95.5% fresh water and 5.5% wastewater
Source of dilution water was: recycled water from pond 10

Was dilution ratio changed during the course of the study? No
Yes__, dilution ratio became __% fresh water and ___% wastewater
Data in table, Items 25 and 26 is for initial dilution___ final dilution___

19. Avg. daily warm season flows (non-storm flows):
Influent 34,750 liters/day Effluent ? liters/day * currently developing H20 budget

20. Avg. daily cool season flows (non-storm):
Influent 34,750 liters/day Effluent ? liters/day

21. Describe flow controls at influent end of system(i.e., valves, swivel pipe, pump on timer, etc.)
~~recycle water - pump on timer~~
wastewater - electric ball valave on timer
flows to pond -1" manual ball valves

22. Any problems with clogging of influent pipes/ valves with debris, struvite, animals, etc.?
No problems when operating all ponds at same detention time.
We are nowhaving problems with operating 2 ponds at 2 day DT and 4 ponds at 7 days.
Methods of control, if applicable:

23. Describe water level controls in the cells (i.e.,downstream swivel pipe):
PVC standpipe cut to proper height

24. Any clogging of pipes between cells or from final outlet cells? No

Methods of control, if applicable:

25. Provide average concentrations in mg/L (or other appropriate units) for influent into the system and effluent from the system for warm (April - October) and cold (November - March) seasons.

Average for the system

Parameter W=warm season C=cold season	Average Concentration or Reading		
	Influent	Effluent	Percent Change
BOD5 (W)	981	290	70
BOD5 (C)	471	208	56
COD (W)	2,812	1,245	56
COD (C)	1,686	896	47
NH_3+NH_4-N (W)	166	82	51
NH_3+NH_4-N (C)	88	52	41
Org-N (W)	225	109	52
Org-N (C)	117	68	42
Total P (W)	44.9	22.7	50
Total P (C)	20.6	12.4	40
PO_4-P (W)	---	---	---
PO_4-P (C)	4.9	1.9	*only 61 8 samples
TSS (W)	748	144	81
TSS (C)	336	140	58
D.O. (W)	2.72	0.15	94
D.O. (C)	5.14	0.28	95
Fecal coliforms (W) (No./100 ml)	907,000	78,000	91
Fecal coliforms. (C) (No./100 ml)	1,520,000	211,000	86
Fecal strep. (W)			
Fecal strep. (C)			
pH (W) (standard units)	7.43	7.14	4
pH (C)	7.50	7.10	5
Water temp. (W) (deg. C)	12.9	12.1	--
Water temp. (C)	7.6	7.3	--
Total Solids (w)	3,329	1,736	48
Total Solids (c)	1,586	958	35

26. Provide same information for <u>only the upstream cell(s)</u>. If a bank of cells is used, provide average data for that bank of upstream cells.

Upstream cell(s)

Parameter W=warm season C=cold season	Average Concentration or Reading		
	Influent	Effluent	Percent Change
BOD5 (W)			
BOD5 (C)			
COD (W)			
COD (C)			
NH_3+NH_4-N (W)			
NH_3+NH_4-N (C)			
Org-N (W)			
Org-N (C)			
Total P (W)			
Total P (C)			
PO_4-P (W)			
PO_4-P (C)			
TSS (W)			
TSS (C)			
D.O. (W)			
D.O. (C)			
Fecal coliforms (W) (No./100 ml)			
Fecal coliforms. (C) (No./100 ml)			
Fecal strep. (W)			
Fecal strep. (C)			
pH (W) (standard units)			
pH (C)			
Water temp. (W) (deg. C)			
Water temp. (C)			

27. For the data in the above tables, what was the period of observation?

mo._____ yr. _____ to mo. _____ yr. _____

28. How many sampling days were included in the study? 27 days

29. What were maximum and minimum influent concentrations for:

a. Ammonia ($NH_3 + NH_4$-N): Max. 301 mg/L Min. 12 mg/L
b. Total suspended solids: Max 1,705 mg/L Min. 75 mg/L
c. Total phosphorus (TP): Max 115 mg/L Min 3.5 mg/L
d. Phosphate (PO_4-P): Max 12.0 mg/L Min 1.2 mg/L Note only 8 samples

30. Which of the following represented a problem at your site (Elaborate as needed or place N/A if not applicable):

a. Insects destroyed particular plant species:
N/A

b. Muskrats or other animals created problems:
Nutria destroyed vegetation and burrowed through berms during construction.

Electric fence was installed around entire site.

c. Plants were killed at upper end of cells because concentrations of ammonia or suspended solids were too high:
N/A. We are interested in what causes death of plants. We conducted a study and found that high ammonia (71,000 mg/l) did not inhibit wetland plant seed germination. We think the death of plants may be volatile acids.

d. Evaporation rates were so high in summer that plants at lower end of system were killed or stressed:
N/A

e. Discharge limits could not be met for certain constituents in the final effluent:

List: N/A no discharge

f. Phosphorus concentrations in the final effluent tended to increase over time:
N/A

g. Water management is a major problem. A water balance should be developed for any new systems which include:
(1) drawing down lagoon levels in late fall to accommodate winter storage of flush water and waste, rainwater on the lagoon surface, and runoff water;
(2) controlling water released to wetland system based on seasonal changes;

(3) collecting water discharged from the system and recycling or land applying;
(4) accounting for rainwater on the surface of the wetlands.

(comments on need for water balance)
All four are extremely important for interpretation of concentrations.
In July 1995 we installed a H20 level recorder in pond 10 to help us construct a H20 balance for oür site.

h. Mosquitoes were a problem: N/A

i. Uneven distribution of wastewater across all cells in a multi-cell system: Only after switching to 2 and 7 day retention times.

j. Others: N/A

More thoughts on problems included on separate sheet □

31. What place do construced wetlands have in managing animal wastes? What are the drawbacks? Should they be permitted for discharge?

I. Two main purposes:
   1) for mass removal of nutrients, solids, and organics. which would reduce amount of wastewater that would need to be disposed of.
   2) for final polishing of pretreated wastewater before discharge.

II. Drawbacks: Require large land area.

III. Depends on circumstances but generally yes.

32. What additional research is needed on these systems?

Design criteria and a better understanding of internal processes.

1c. Information on cooperating researchers:

Mike J. Gamroth
Animal Science Department
Oregon State University
Corvallis, OR 97330
Ph: (541) 737-3316 FAX: (541) 737-4174

Co-investigator

1d. Steven M. Skarda
Dept. of Bioresource Engineering
Oregon State University
Corvallis, OR 97330
Ph: (541) 737-6296 FAX: (541) 737-2082

Lab Technician

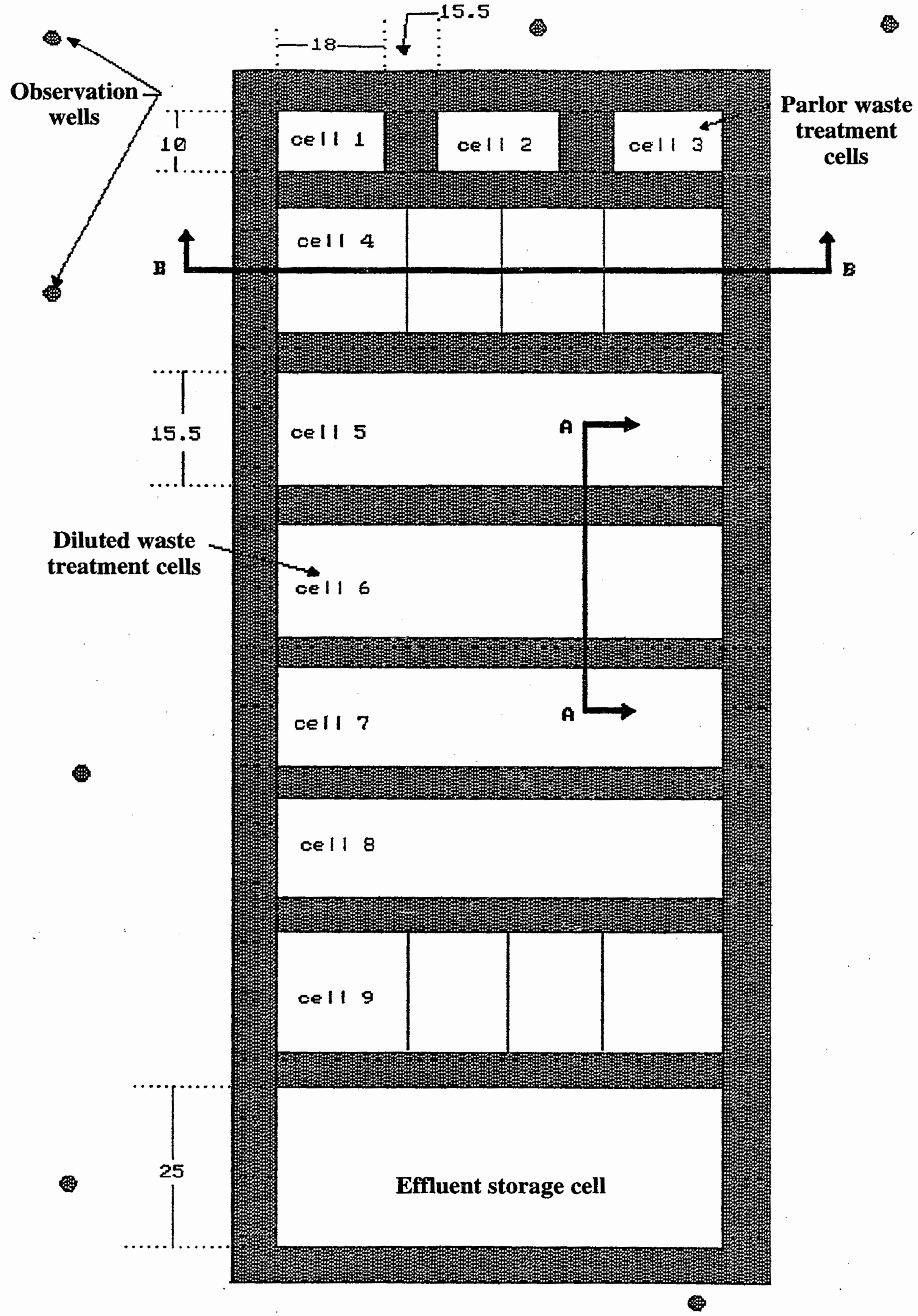


Figure 1: Plan View of OSU Constructed Wetland Cells

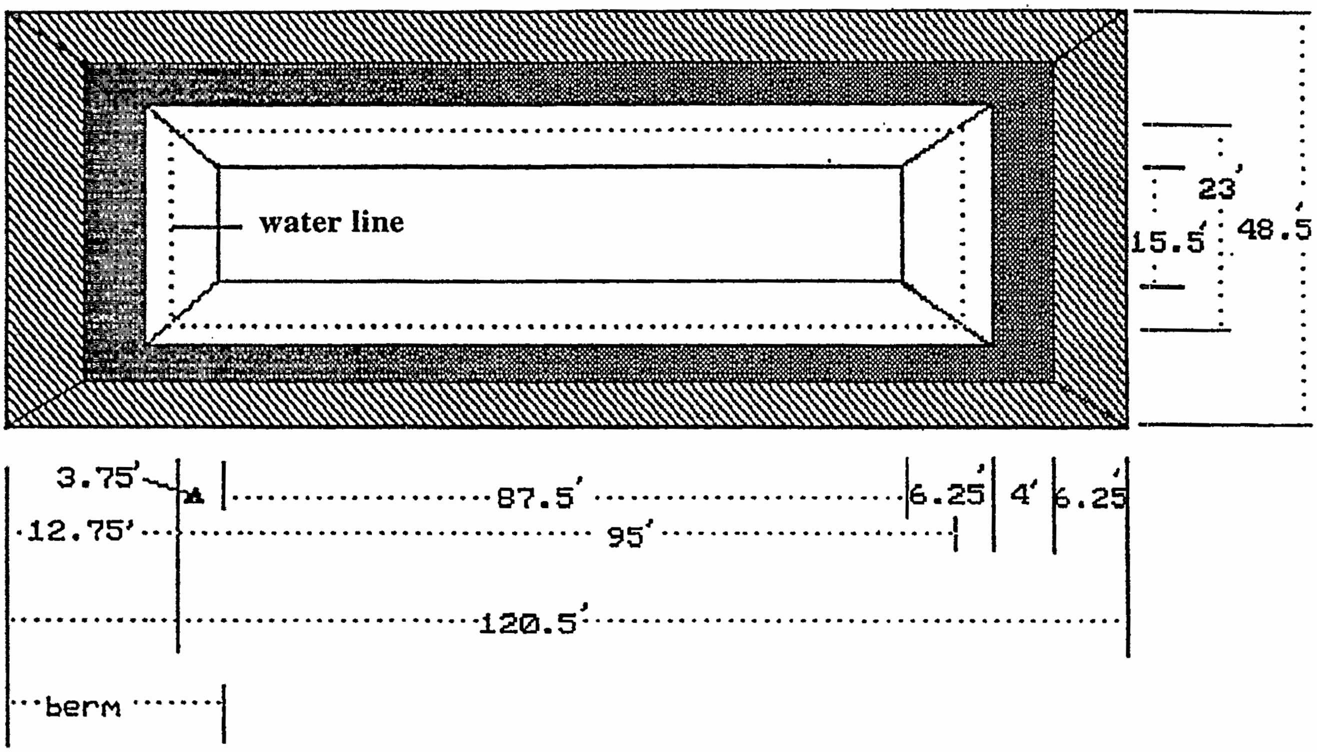


Figure 2: Dimensions of Constructed Cells

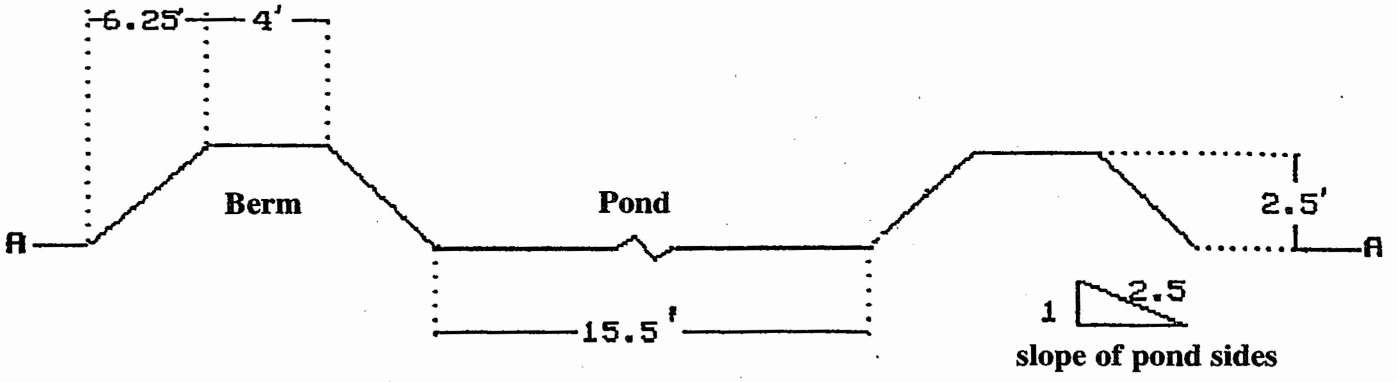


Figure 3: Cross section "A" of Wetland Cells

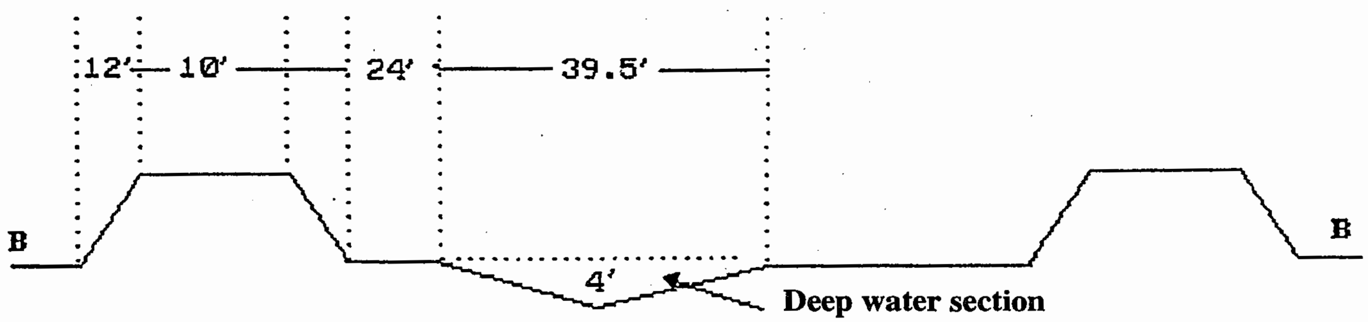


Figure 4: Cross section "B" of Wetland Cells

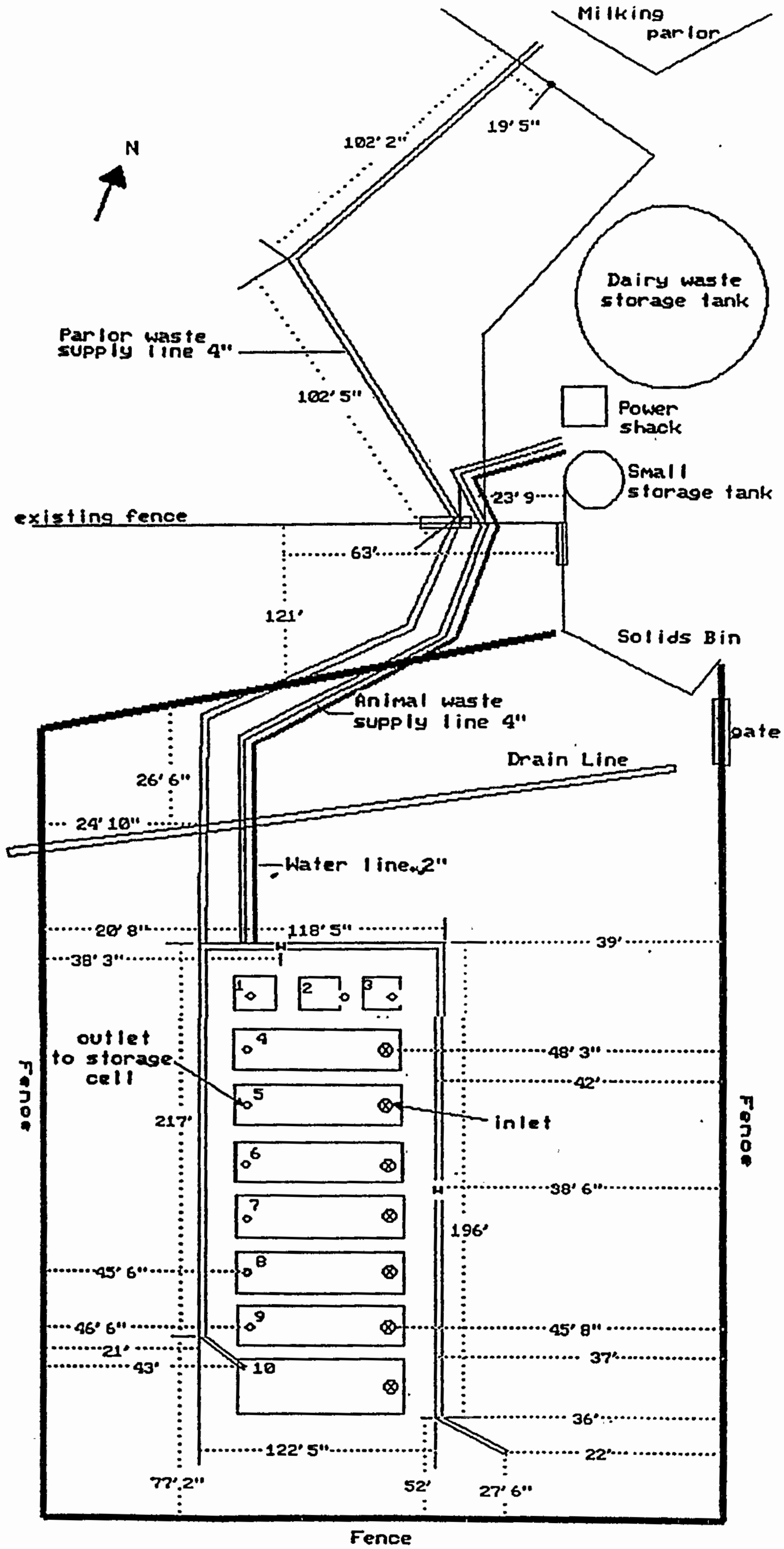


Figure 5: OSU Constructed Wetlands Piping Schematic

CONSTRUCTED WETLANDS
FOR TREATING ANIMAL WASTES
QUESTIONNAIRE

1. Information on person(s) completing this questionnaire or cooperating researchers:

   a. Name: David T. Hill

   Address: Agricultural Engineering Dept
   Auburn University
   Auburn University, AL 36849-5417

   Phone: 334-844-3531 FAX: 334-844-3530

   Your involvement / experience with this wetland system:

   Researcher, Operator

   b. Name: ____________________

   Address: ____________________

   ____

   ____

   Phone: ____________ FAX: ____________

   Your involvement / experience with this wetland system:

   ____

   ____

   Others included on separate sheet: 1c. ☐ 1d. ☐

2. Location of the system (description or address): Ala. Agricultural Experiment Station, Poultry Research Unit, Auburn University, AL

   Location in terms of latitude and longitude: Lat. 32 36.87 Long. 85 25.86

3. Approximate percentage of funding for this project was provided by:

   EPA ___% State Water Quality Agency ___% TVA ___% USDA 40 %

   State Experiment Station 60 % Other ____________________

4. Animal information:

Type: Poultry — Number: 10,000 layers — Avg. Wgt. 1.8 kg
Type: ______ — Number: ______ — Avg. Wgt. ______
Type: ______ — Number: ______ — Avg. Wgt. ______
Type: ______ — Number: ______ — Avg. Wgt. ______
Type: ______ — Number: ______ — Avg. Wgt. ______

5. Date wetland system was installed: yr. 1992 month June
6. Date system became operational (first waste discharge): yr 1992 month Oct
7. Type of pre-treatment (check one or describe):
   One cell lagoon ___ Two lagoon cells ___
   Waste Storage Pond (as defined by SCS or NRCS): ___
   Settling Basin ___
   Other: Three lagoon cells; most wastewater delivered to wetland from cell #1

8. Approximate age of pre-treatment units when wetland became operational: 17 yrs

9. Had sludge ever been removed from the pre-treatment unit prior to installation of the wetland system? yes x ; 1 yrs prior to installing wetland. no ___

10. Basis for design of wetland system (i.e., 90 lbs BOD/ac/day; minimum 7 day detention time; etc.) If a wetland / pond / wetland system was used, include design basis for pond and for entire system: 65 lbs BOD/ac/day, 11 day HRT

11. Whose design criteria did you use? (TVA, SCS, private industry, etc.) List any references:

USDA-SCS

12. Total surface area (water surface) of wetland cells: 781 m^2 or ______ acres

13. Total surface area of pond cells: 3250 m^2 or ______ acres

14. Surface area of the entire system including embankments: 4031 m^2 or ______ acres

15. Average water depth: 25 cm

16. Average slope of cells from upstream to downstream: 1 %

17. Provide a sketch in plan view showing all cells, embankments, and general location in relation to pretreatment units and other significant features. Provide dimensions for the cells and embankments. If preferred, attach engineering drawings or drawings from a publication and note here.

18. Was the waste flow diluted prior to being discharged into the wetland system? No_x*_

Yes__, dilution ratio was __% fresh water and __% wastewater

Source of dilution water was:____

(* Wastewater was dilute for a poultry facility because of high water use for flushing.)

Was dilution ratio changed during the course of the study?

Yes__, dilution ratio became __% fresh water and ___% wastewater

Data in table, Items 25 and 26 is for initial dilution___ final dilution___

19. Avg. daily warm season flows (non-storm flows):

Influent _2500_ liters/day Effluent ____ liters/day

20. Avg. daily cool season flows (non-storm):

Influent _2500_ liters/day Effluent ____liters/day

21. Describe flow controls at influent end of system(i.e., valves, swivel pipe, pump on timer, etc.)

____Valves____

22. Any problems with clogging of influent pipes/ valves with debris, struvite, animals, etc.?

________Yes____

Methods of control, if applicable:

__________Manual cleaning__________________________

23. Describe water level controls in the cells (i.e.,downstream swivel pipe): ______________

__________Downstream swivel pipe___________________

24. Any clogging of pipes between cells or from final outlet cells? ________Yes__________

Methods of control, if applicable: ________Manual cleaning____________________

25. Provide average concentrations in mg/L (or other appropriate units) for influent into the system and effluent from the system for warm (April - October) and cold (November - March) seasons.

Average for the system

Parameter W=warm season C=cold season	Average Concentration or Reading		
	Influent	Effluent	Percent Change
BOD5 (W)	135.0	46.2	63.8
BOD5 (C)	260.0	155.0	40.4
COD (W)	400.0	205.0	48.8
COD (C)	300.0	155.0	48.3
NH_3+NH_4-N (W)	80.0	51.2	36
NH_3+NH_4-N (C)	110.0	72.1	34.5
Org-N (W)	25.0	5.5	78
Org-N (C)	20.0	7.2	64
Total P (W)	30.0	17.1	43
Total P (C)	22.0	17.2	21.8
PO_4-P (W)			
PO_4-P (C)			
TSS (W)			
TSS (C)			
D.O. (W)			
D.O. (C)			
Fecal coliforms (W) (No./100 ml)			
Fecal coliforms. (C) (No./100 ml)			
Fecal strep. (W)			
Fecal strep. (C)			
pH (W) (standard units)	7.2	7.2	
pH (C)	7.7	7.3	
Water temp. (W) (deg. C)	86.6 F	85.5 F	
Water temp. (C)	55.6 F	54.2 F	

26. Provide same information for <u>only the upstream cell(s)</u>. If a bank of cells is used, provide average data for that bank of upstream cells.

Upstream cell(s) ----- NOT TAKEN---

Parameter W=warm season C=cold season	Average Concentration or Reading		
	Influent	Effluent	Percent Change
BOD5 (W)		Same as wetland influent	
BOD5(C)			
COD (W)			
COD(C)			
NH_3+NH_4-N (W)			
NH_3+NH_4-N (C)			
Org-N (W)			
Org-N (C)			
Total P (W)			
Total P (C)			
PO_4-P (W)			
PO_4-P (C)			
TSS (W)			
TSS (C)			
D.O. (W)			
D.O. (C)			
Fecal coliforms (W) (No./100 ml)			
Fecal coliforms. (C) (No./100 ml)			
Fecal strep. (W)			
Fecal strep. (C)			
pH (W) (standard units)			
pH (C)			
Water temp. (W) (deg. C)			
Water temp. (C)			

27. For the data in the above tables, what was the period of observation?

mo. _8_ yr. _93_ to mo. _3_ yr. _94_

28. How many sampling days were included in the study? 14 days

29. What were maximum and minimum influent concentrations for:

a. Ammonia ($NH_3 + NH_4$-N): Max. 126 mg/L Min. 72.2 mg/L
b. Total suspended solids: Max ______ mg/L Min. ______ mg/L
c. Total phosphorus (TP): Max 36.5 mg/L Min 15 mg/L
d. Phosphate (PO_4-P): Max ______ mg/L Min ______ mg/L

30. Which of the following represented a problem at your site (Elaborate as needed or place N/A if not applicable):

a. Insects destroyed particular plant species:

NO

b. Muskrats or other animals created problems:

NO

c. Plants were killed at upper end of cells because concentrations of ammonia or suspended solids were too high:

NO

d. Evaporation rates were so high in summer that plants at lower end of system were killed or stressed:

NO

e. Discharge limits could not be met for certain constituents in the final effluent:
List: We weren't concerned with discharge limits

f. Phosphorus concentrations in the final effluent tended to increase over time:

Only in the cool season

g. Water management is a major problem. A water balance should be developed for any new systems which include:
(1) drawing down lagoon levels in late fall to accommodate winter storage of flush water and waste, rainwater on the lagoon surface, and runoff water;
(2) controlling water released to wetland system based on seasonal changes;
(3) collecting water discharged from the system and recycling or land applying;

(4) accounting for rainwater on the surface of the wetlands.

(comments on need for water balance)

This was a research unit. We were not concerned with lagoon operation. We maintained constant flow to the wetland cells.

h. Mosquitoes were a problem: Yes-- but they were not biting mosquitoes

i. Uneven distribution of wastewater across all cells in a multi-cell system: No

j. Others: Influent pipe plugging

More thoughts on problems included on separate sheet ☐

31. What place do constructed wetlands have in managing animal wastes? What are the drawbacks? Should they be permitted for discharge?

Wetlands are questionable for managing animal wastes. they do not provide for final disposal and are only another intermediate treatment-- and a headache at that. I do not see them enjoying a "place in the sun" in animal waste management operations. Phosphorus build-up over years will be the main problem. In short, they are more trouble than they are worth. Should not be permitted for discharge.

32. What additional research is needed on these systems?

Water balance, temperature variation caused by plants

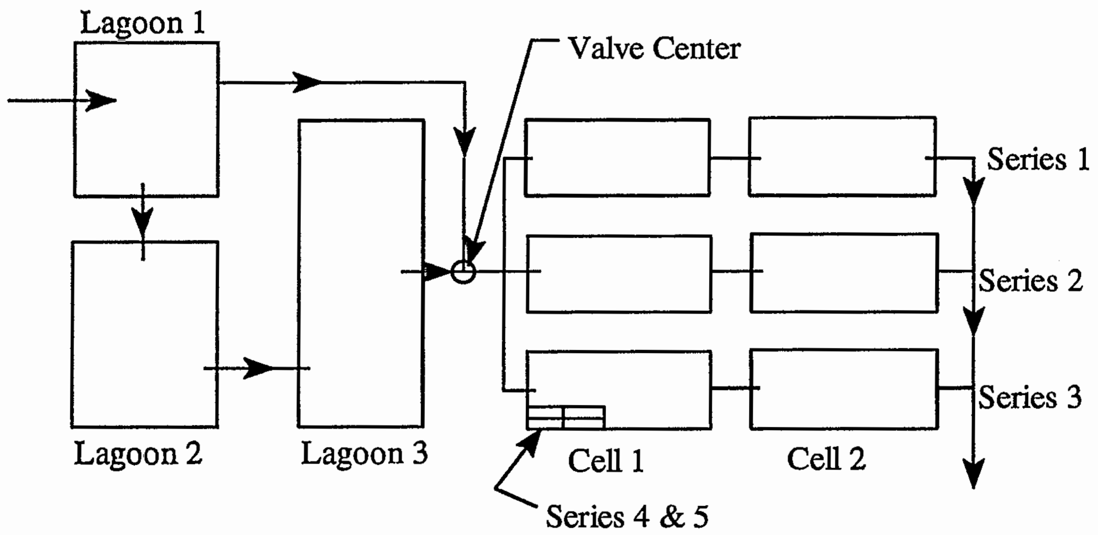
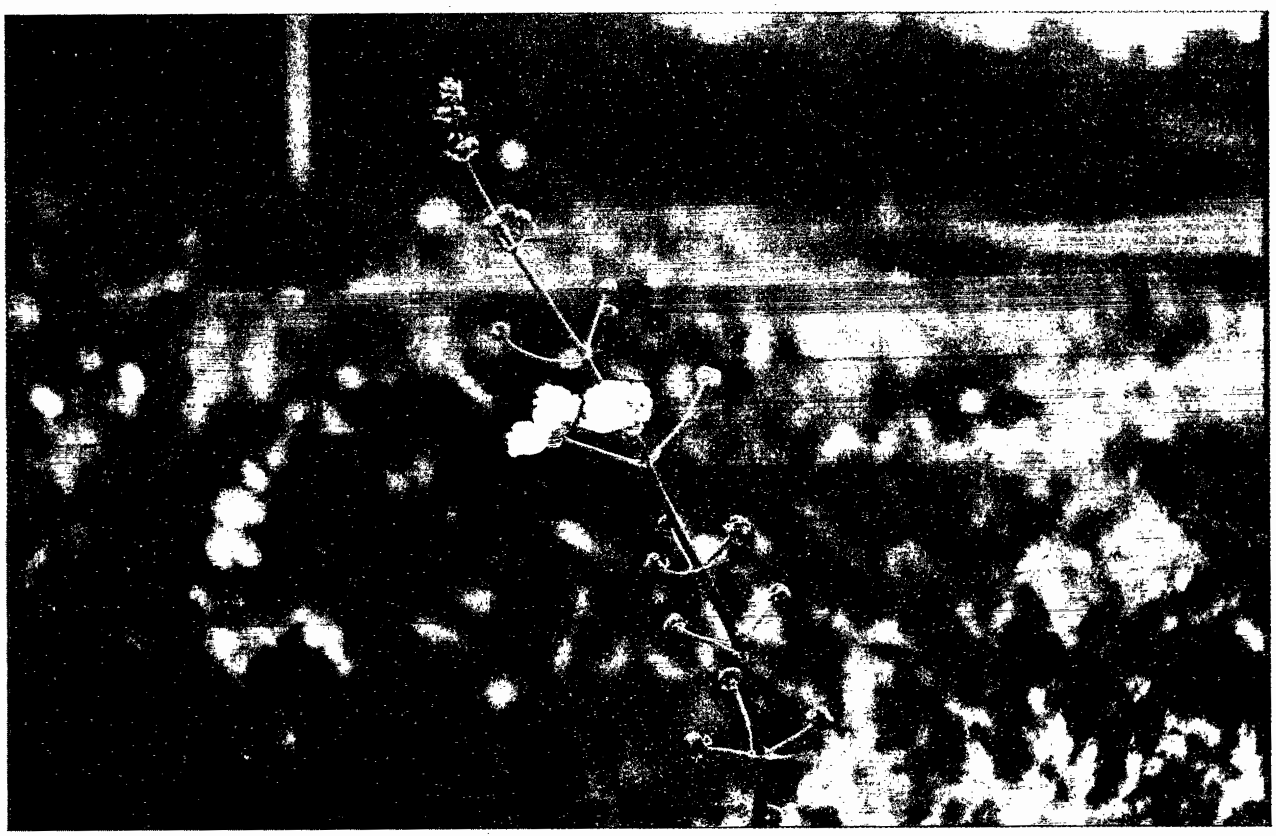


Figure 1. Overview of the lagoon and constructed wetland treatment system at Auburn University's Poultry Research Unit

Constructed Wetlands for Animal Waste Treatment

Appendix B
Typical Aquatic Plants Used in Animal Waste Treatment Constructed Wetlands



Typical Aquatic Plants Used for Animal Waste Treatment Wetland

A wide variety of species of wetland plants have been used in municipal waste treatment. The same cannot be said of wetlands used to treat animal wastes. Some species have been planted in animal waste wetlands but have either not survived because of wastewater strength or because they could not compete successfully with more tolerant or more aggressive species.

Presented here are a few species that have performed successfully in the animal waste environment. Most have been purposefully introduced but others are natural invaders. Certain species which were purposefully introduced in one place might be natural invaders in another.

Hydrocotyle umbellata (Water pennywort, marsh pennywort)

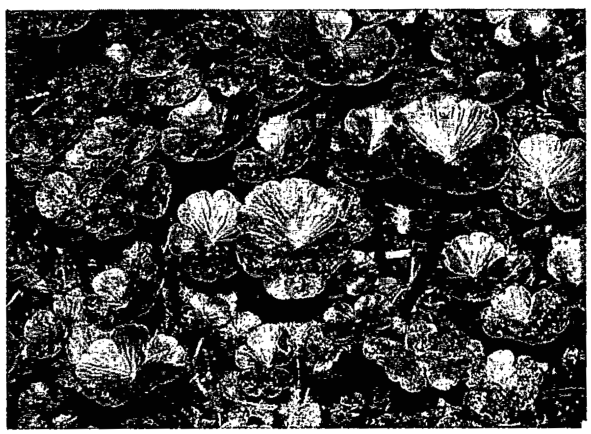
The growth habit of the marsh pennywort is a cross between emergent and floating. It is a common natural invader in animal waste constructed wetlands. Since it tolerates partial shade, it readily occupies open areas between taller emergent plants.

The most characteristic feature of marsh pennywort is its circular leaves. Each leaf is centrally attached on a long, slender stem; it is scalloped on the edges with the scallops appearing as shallow rounded teeth (crenate margins). Small white flowers are produced in simple, many-flowered clusters; each cluster is formed on a narrow stem which often rises above the height of the leaves.

Vegetative growth method: stolons or rhizomes
Growth and spread rate: rapid
Persistence: perennial, non-persistent
Spacing when planted: N/A
Water regime: regular to permanent inundation, <12 in (30 cm)

Other comments: Has proliferated in the first cell of an animal waste wetland with NH_4 concentrations greater than 80 ppm.

Pennywort spreads across open areas between taller plants in this wetland.



Pennywort's rounded, crenate leaf

Iris versicolor, virginicus (Blue flag)

Blue flag is an elegant plant which produces a large, pale blue to purple flower. The

flower resembles the domestic, garden-variety Dutch iris. The leaves are narrow, flat and pointed, and they arise like a fan from the base of the plant.
Blue flag has been used successfully in on-site, subsurface constructed wetlands and in municipal systems. Although it has been planted in wetlands for treating animal wastes, it has not been as successful. It would probably fair best in a second or third cell where wastewater strength has been diminished. Without assistance, it may not compete well with more vigorous species.

Vegetative growth method: bulb
Growth and spread rate: slow, <2 ft (60 cm)/yr
Persistence: perennial, persistent
Spacing when planted: 0.5-1.5 ft (15-45 cm)
Water regime: regular to permanent inundation, 6 in (15 cm)

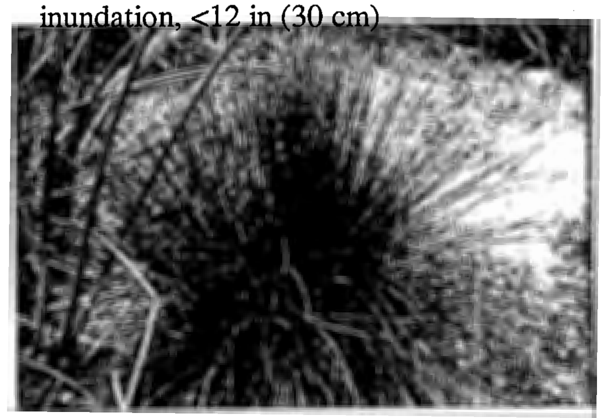
Blue flag (Iris versicolor, virginicus)

Juncus effusus (Soft rush)

Rushes are grass-like, emergent plants which grow in clumps. The pale green stems are cylindrical and grow to 2 to 5 ft (0.6 - 1.5 m) tall. Flowers are produced on floral axis (inflorescence) which is open and branched. This flowering axis appears from late spring through fall and emerges from the side of the plant.

Juncus has been planted and survived in animal waste wetlands. In some cases they have been crowded out by other species.

Vegetative growth method: rhizomes
Growth and spread rate: slow, <15 in (6 cm)/yr
Persistence: perennial, persistent
Spacing when planted: 0.5-1.5 ft (0.15-0.45 m) O.C.
Water regime: regular to permanent inundation, <12 in (30 cm)



Soft rush (Juncus effusus)

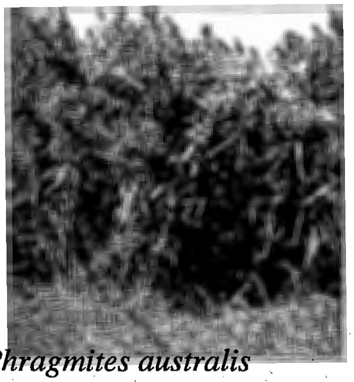
Phragmites australis (Common reed)

Phragmites is a perennial grass which establishes itself quickly and spreads rapidly through its rhizomes. The stems of the plant are slender and may reach 9 to 10 ft (2.7 - 3.0 m) tall. The leaf blades are about $1^1/_4$ in (3.2 cm) wide and about a foot (0.3 m) long. Silky white hairs about $^1/_4$ in (0.6 cm) long are located at the junction of the leaf sheath and blade.

The stems of this plant are leafy up to the flowering head. The flower head or panicle is a loose, feathery cluster of flowers which may be over a foot (0.3 m) long. It will be tawny, brown, purplish or silvery in color. As the panicles age, the color becomes more silvery due to the long hairs associated with the flowers or spikelets.

Vegetative growth method: rhizomes
Growth and spread rate: rapid, >1 ft (30 cm)/yr
Persistence: perennial, persistent
Spacing when planted: 2.0-6.0 ft (0.6-1.8 m)
Water regime: seasonal to permanent inundation, up to 2 ft (60 cm)

Other comments: Because of its aggressive growth habits, *Phragmites* may be considered to be a pest plant in some parts of the country, and its use in constructed wetlands may be discouraged. However, it has performed well in animal waste wetlands where relatively high pollutant loads occurred.

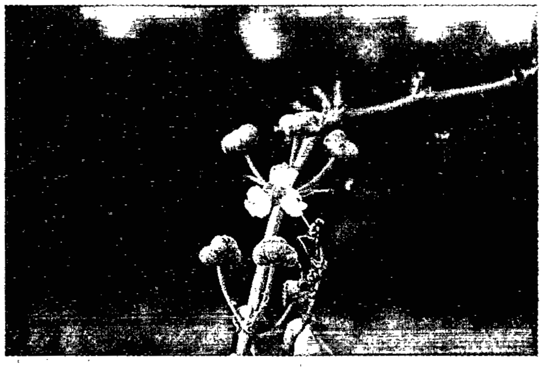


Phragmites australis

Sagittaria spp.
(Duck potato, arrowhead)

Duck potato has large, thick leaves and conspicuous white flowers. It gets its name from the potato-like corms often produced underground. *Sagittaria* consists of several species whose leaves can vary considerably in size and shape. Two species which have been used successfully in animal waste constructed wetlands include *S. lancifolia* and *S. latifolia*. They are generally good competitors with other more aggressive species.

The leaves are typically 4 in (10 cm) wide and up to 2 ft (1.6 m) long and grow as a fan-like rosette from underground rhizomes. The base of the plants are full and can mound above the water level in shallow water.



Sagittaria latifolia in bloom

The white flowers are showy with three petals. They are on thick stalks that often extend a foot (0.3 m) or more above the leaves.

Mounded base of Sagittaria plants

Vegetative growth method: runners, tubers
Growth and spread rate: rapid, >1 ft (30 cm)/yr
Persistence: perennial, non-persistent
Spacing when planted: 2-6 ft (0.6-1.8 m)
Water regime: regular to permanent inundation, up to 2 ft (60 cm)

Other considerations: The mounds which form at the base of the plants may, as the wetland matures, affect water flow and hydraulic retention time. More information will be needed on this topic.

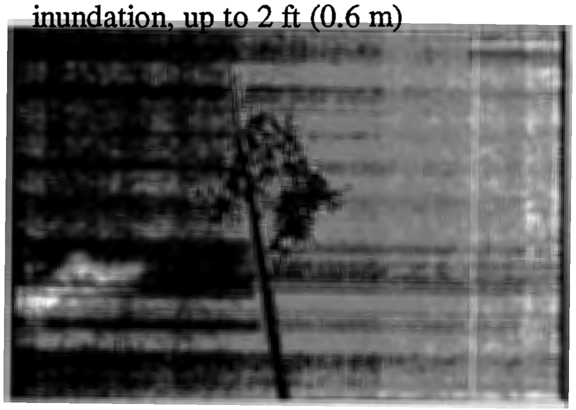
Scirpus **sp. (Bulrush)**

Several species of *Scirpus* have been used in municipal wastewater treatment. A common variety used for animal waste treatment is *S. validus* (soft stem bulrush).

A colony of bulrush

S. validus typically grows in colonies and can reach 10 ft (3 m) in height. The stems are about 3/4 in (2 cm) thick at the base and taper to a point at the top. The bulrush does not have obvious leaves, but only sheaths at the base of the stem. A floral axis appears at the top of the stem and has several drooping stalks that have irregularly clustered spikelets.

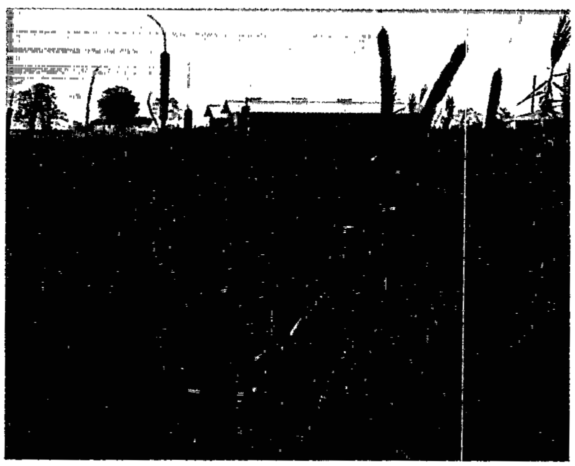
Vegetative growth method: rhizomes
Growth and spread rate: rapid, >1 ft (30 cm)/yr
Persistence: perennial, persistent
Spacing when planted: 2 - 6 ft (0.6 - 1.8 m)
Water regime: regular to permanent inundation, up to 2 ft (0.6 m)



The floral axis at the top of a bulrush stem

Typha **spp. (Cattail)**

Cattails are perhaps the most easily recognized of all wetland plants. They grow prolifically in animal waste constructed wetlands and appear to be as adaptable to high strength wastes as any plant.



The flower spike of cattail

The plant gets its name from the cylindrical flower spike which is packed with tiny flowers. The spikes are cinnamon brown and the leaves can reach 7 ft (2.1 m) in height. The spikes can grow more than a foot long.

The cattail leaves are flat with rounded backs. They are typically 1 in (2.5 cm) wide and can grow to 5 to 8 ft (1.5 - 2.4 m) tall. The leaves are sheathed together at the base.

Vegetative growth method: rhizomes
Growth and spread rate: rapid, >1 ft (30 cm)/yr
Persistence: perennial, persistent
Spacing when planted: 1 - 6 ft (0.6 - 1.8 m)
Water regime: irregular to permanent inundation, up to 1 ft (30 cm)
Other comments: Cattails are sometimes attacked by caterpillars which strip the leaves. This is a temporary occurrence and the plants revive. The effect on treatment is thought to be inconsequential.

A caterpillar attacks the leaf of this cattail

Zizaniopsis miliacea
Giant cutgrass, Southern wild rice

Cutgrass is a perennial grass that grows to 10 ft (3 m) tall. It forms very dense stands and has proliferated in animal waste constructed wetlands. It has not been a natural invader of these wetlands.
The stems are single leaf blades with widths of 1 ½ to 2 ½ in (3.8 - 6.4 cm). The margins of the blades are upwardly scabrous (cutting or rough to the touch), hence the name "cutgrass."

A stand of cutgrass in the second cell of a wetland used to treat swine lagoon effluent.

The flowers of the plant form on a floral axis, which is a loose and irregular branching cluster or panicle. These panicles will reach 1 to 2 ft (30 to 60 cm) in height. Flowering occurs from April to July in the South.

Vegetative growth method: rhizomes
Growth and spread rate: rapid
Persistence: perennial, persistent
Spacing when planted: 2- 4 ft (0.6 - 1.2 m)
Water regime: regular to permanent inundation, up to 3 ft (0.9 m)

References:

CH2M Hill and Payne Engineering (1997), *Constructed Wetlands for Livestock Wastewater Management: Literature Review, Database, and Research Synthesis*;

prepared for the EPA's Gulf of Mexico Program through the National Council of the Paper Industry for Air and Stream Improvement (NCASI) and the Alabama Soil and Water Conservation Committee; Montgomery, AL.

Aulbach-Smith, C. A. and S. J. de Kozlowski (1990); Aquatic and Wetland Plants of South Carolina; South Carolina Aquatic Plant Management Council *in cooperation with* South Carolina Water Resources Commission; Columbia, SC

Constructed Wetlands for Animal Waste Treatment

Appendix C
As-Excreted Waste and Wastewater Production Values for Livestock and Poultry

Wastewater Volumes and As-Excreted Waste Values

Table C-1. Swine: As-Excreted Values

Constituent	Units*	Growers 18.1 - 99.8 kg (40 - 220 lbs)	Replacement Gilts	Sows		Boars	Nursing/ Nursery Pigs 2.7-18.1 kg (6 - 40 lb)
				Gestation	Lactation		
Mass	kg/d	28.8	14.9	12.3	27.2	9.3	48.1
	(lb/d)	(63.4	(32.8)	(27.2)	(60.0)	(20.5)	(106)
Volume	m^3/d	0.028	0.015	0.012	0.027	0.009	0.048
	(ft^3/d)	(1.0)	(0.53)	(0.44)	(0.96)	(0.33)	(1.70)
Nitrogen	kg/d	0.19	0.11	0.09	0.21	0.07	0.27
	(lb/d)	(0.42)	(0.24)	(0.19)	(0.47)	(0.15)	(0.60)
Phosphorus	kg/d	0.07	0.04	0.03	0.07	0.23	0.11
	(lb/d)	(0.16)	(0.08)	(0.063)	(0.15)	(0.05)	(0.29)
BOD_5	kg/d	0.94	0.49	0.38	0.91	0.30	1.54
	(lb/d)	(2.08)	(1.08)	(0.83)	(2.00)	(0.65)	(3.40)

Table C-2. Dairy: As-Excreted Values

Constituent	Units*	Cow		Heifer
		Lactating	Dry	
Mass	kg/d	36.3	37.2	38.6
	(lb/d)	(80.0)	(82.0)	(85.0)
Volume	m^3/d	0.037	0.037	0.037
	(ft^3/d)	(1.30)	(1.30)	(1.30)
Nitrogen	kg/d	0.20	0.16	0.14
	(lb/d)	(0.45)	(0.36)	(0.31)
Phosphorus	kg/d	0.032	0.023	0.018
	(lb/d)	(0.07)	(0.05)	(0.04)
BOD_5	kg/d	0.73	0.54	0.59
	(lb/d)	(1.60)	(1.20)	(1.30)

*Units per 454 kg (1,000 lb) of animal weight; Source: USDA-NRCS, 1992.

Table C-3. Beef: As-Excreted Values

Constituent	Units*	Feeder 340 - 499 kg (750 - 1,100 lb)		Yearling 205 - 340 kg (450 - 750 lb)	Cow
		High Forage Diet	High Energy Diet		
Mass	kg/d	26.8	23.2	26.4	28.6
	(lb/d)	(59.1)	(51.2)	(58.2)	(63.0)
Volume	m^3/d	0.027	0.023	0.026	0.028
	(ft^3/d)	(0.95)	(0.82)	(0.93)	(1.00)
Nitrogen	kg/d	0.14	0.13	0.14	0.15
	(lb/d)	(0.31)	(0.30)	(0.30)	(0.33)
Phosphorus	kg/d	0.05	0.043	0.045	0.054
	(lb/d)	(0.11)	(0.094)	(0.10)	(0.12)
BOD_5	kg/d	0.62	0.62	0.59	0.54
	(lb/d)	(1.36)	(1.36)	(1.30)	(1.20)

Table C-4. Poultry Layers: As-Excreted Values

Constituent	Units*	Layer Hen
Mass	kg/d	27.4
	(lb/d)	(60.5)
Volume	m^3/d	0.026
	(ft^3/d)	(0.93)
Nitrogen	kg/d	0.38
	(lb/d)	(0.83)
Phosphorus	kg/d	0.14
	(lb/d)	(0.31)
BOD_5	kg/d	1.68
	(lb/d)	(3.70)

*Units per 454 kg (1,000 lb) of animal weight; Source: USDA-NRCS, 1992.

Table C-5. Volume of Milkhouse and Parlor Wastes

Washing Operation	Water Volume		Volume Per
	Liters	Gallons	
Bulk tank			
Automatic	140 - 230	50 - 60	wash
Manual	115 - 150	30 - 40	
Pipeline			
In parlor	240 - 475	75 - 125	wash
Miscellaneous equipment	115	30	day
Cow preparation			
Automatic (estimated avg.)	7.6	2	wash/cow
Manual	0.95 - 1.9	0.25 - 0.50	
Milkhouse floor	40 - 75	10 - 20	day
Parlor floor w/o flushing	150 - 285	40 - 74	day
Parlor and holding area with flushing			
Parlor only	75 - 115	20 - 30	cow/day
Parlor and holding area	95 - 150	25 - 40	
Holding area only	40 - 75	10 - 20	

Table C-6. Minimum Total Daily Flush Volumes for Swine

Swine type	Flush Volume	
	L/head	Gal/head
Sow and litter	130	35
Pre-nursery	8	2
Nursery pig	15	4
Growing pig	40	10
Finishing pig	60	15
Gestating sow	95	25

Constructed Wetlands for Animal Waste Treatment

Appendix D
Conversion Tables

Conversion Table

Area	multiply by	Length	multiply by
ft^2 ➽ m^2	9.2903×10^{-2}	ft ➽ m	0.3048
m^2 ➽ ft^2	10.764	m ➽ ft	3.2808
ac ➽ ha	0.4047	mile ➽ km	1.6093
ha ➽ ac	2.471	km ➽ mi	0.5907
Flowrate	**multiply by**	**Volume**	**multiply by**
ft^3/s ➽ m^3/s	2.8317×10^{-2}	ft^3 ➽ m^3	2.8317×10^{-2}
m^3/s ➽ ft^3/s	35.314	m^3 ➽ ft^3	35.31
gal/min ➽ L/s	6.309×10^{-2}	gal ➽ L	3.7854
L/s ➽ gal/min	15.85	L ➽ gal	0.264
Mass	**multiply by**	**Wgt/area**	**multiply by**
lb ➽ kg	0.454	lb/ac ➽ kg/ha	1.12
kg ➽ lb	2.204	kg/ha ➽ lb/ac	0.89

Temperature:	°F = 1.8(C°) + 32	°C = 0.5556(°F - 32)

Milligrams per liter (mg/L): 1 mg/L is 1 milligram (mass) in 1 million parts (volume..i.e., liter). If the liquid has a specific gravity similar to water, 1 mg/L = 1 ppm. In concentrations below about 7,000 mg/L this relationship is generally true. A one percent solution has a concentration of 10,000 ppm, which equals 1 gm in 100 grams of water.

One ppm is approximately equal to 1 gallon of water by weight (8.34 lbs) in one million gallons of water (gallons). So, 1 ppm = 8.34×10^{-6} lbs/gal or 0.00834 lbs/1000 gal., assuming a specific gravity similar to water.

In wastewater applications, the fraction of solids can be high, and the relationship between ppm and lbs/gal is not totally accurate. However, for approximation purposes, concentrations of nutrients in wastewater, for example, can be converted from mg/L or ppm to lb/1000 gal by multiplying by 8.34×10^{-3}. Thus, 200 mg/L N would convert to approximately 1.7 lbs N/1000 gal.